



YOUR air YOUR health

A MAJOR NEW STUDY TESTS THE QUALITY OF AIR AND HUMAN HEALTH IN FORT McMURRAY

JUNE 2000

INTRODUCTION

The quality of the air we breathe affects our quality of life – and it affects our health. In 1994, the Alberta Energy and Utilities Board recommended that a study be done on the quality of the air in the community of Fort McMurray, and its potential impact on human health.

Working together, local and provincial health officials, First Nations, environmental groups, oil sands companies, scientists and others wanted to see if a measurable connection could be made between human health and regional industrial activity in the region.

For over a year, and through every season, a team of scientists worked with 300 volunteer participants to test their health, measure the quality of the air they breathed and test the air in Fort McMurray. Today, the results of this study provide a detailed picture of community health, and give us the ability to measure changes over time.

AN INDEPENDENT THIRD-PARTY RESEARCH TEAM

A local and international team of 23 scientists designed the health study, conducted the research and wrote the report. Members of the team came from a wide range of organizations – with an advisory committee to oversee the project, and a science team to conduct the research and analyze the data.

SCIENCE TEAM

- Alberta Health and Wellness
- Alberta Research Council
- Centre for Toxicology
- University of Alberta
- University of Calgary

SCIENCE ADVISORY COMMITTEE

- Harvard School of Public Health
- George Washington University
- World Health Organization
- Health Canada



HOW THE STUDY WORKED...

Working together, the science team developed a comprehensive research program. Technology developed by the Alberta Research Council and Calgary's Centre for Toxicology let researchers consider many factors when looking at the relationship between air quality and human health. Research included:

- 300 volunteers who kept diaries of their activities and wore Personal Exposure Monitors – small badges and air samplers – for up to five days at a time to measure the air they breathed during work, leisure and home time,

- Comparison to a "control group" of volunteers in Lethbridge – a community with little industrial development – to see if any health differences could be found,
- Three types of air monitors – inside and outside the participants' homes, and in the ambient air in Fort McMurray – to measure how air quality changes in each location,
- Special "active" samplers that collected dust in the air – which was studied using electron microscopes, and
- Assessment of local health through blood and urine samples, detailed medical tests and questionnaires, review of regional health information and the volunteers' activity diaries.

UNDERSTANDING OUR AIR: COMMON CONTAMINANTS

The study looked for five main types of contaminants that can affect our air quality, and that are known to have an impact on human health. Also, the scientists used the medical tests to look for evidence of other contaminants that could be affecting people.

VOCs
Volatile Organic Compounds are chemicals that contain carbon, and they evaporate easily into the atmosphere. VOCs can cause odors and form ground-level ozone. Sources of VOCs include gasoline, solvents and dry cleaning chemicals.

O₃
OZONE
 In the high atmosphere, ozone occurs naturally and protects the earth from ultraviolet radiation. But at ground level, ozone is created when nitrogen oxides and VOC's react together in sunlight, generating smog. Ozone is usually higher in rural areas.

NO₂
(NITROGEN DIOXIDE)
 Nitrogen dioxide is a gas that occurs naturally and from human activities. Vehicle exhaust is the largest single source of nitrogen dioxide in Alberta (about 43%) while industrial sources, primarily oil and gas activities, produce about 37% of the total. NO₂ contributes to smog/haze and acid rain.

SO₂
(SULPHUR DIOXIDE)
 Sulphur dioxide is a gas formed during the processing and combustion of fossil fuels containing sulphur. Sources can include gas plant flares, oil refineries, pulp and paper mills, coal-fired power plants and heating boilers. SO₂ contributes to smog/haze and acid rain.

PM
(PARTICULATE MATTER)
 Particulate matter can be many different sizes and composed of many different things including smoke, mould, pollen, minerals and other airborne particles. Any PM that is smaller than 10 microns (about one-fifth the width of a hair) floats in the air and can be inhaled. The study looked at two sizes of PM – those smaller than 10 microns, and very fine particles smaller than 2.5 microns. The smaller dust is, the more easily it is inhaled into the lungs.

THE BIG PICTURE: QUALITY AIR AND A HEALTHY COMMUNITY

After detailed study, the big picture is clear: Fort McMurray residents are breathing good quality air. The study showed that ambient levels of airborne contaminants are low compared to provincial, national and international guidelines, and that personal exposure is low.

In addition to air quality, the study examined both volunteer participant and community health records, and concluded that air emissions from industrial development have produced no measurable negative impact on overall health.

To be more certain, Fort McMurray's volunteers were compared with a group from Lethbridge, where there is little industrial development. No significant differences were found – people showed similar rates of illness, disease, chronic conditions, lung function, neurocognitive function, exposure to contaminants, and death.

THE DETAILS

The volunteers in the study wore badges that measured the contaminants in air they breathed – giving us a picture of their personal exposure to contaminants whether they were at work, outside or at home. The study showed that the average volunteer's personal exposure to contaminants was very low.

HOW MUCH IS SAFE?

The contaminants looked at in this study – SO₂, NO₂, VOCs, O₃, and particulate matter – are found in the air everyone breathes. At low levels, they don't create a risk to our health. But when we are exposed to high levels of any contaminant, the result can be unpleasant and unhealthy.

To determine what is safe, scientists working for the provincial and federal governments establish guidelines. Guidelines change depending on how long you are exposed to contaminants in the air, and usually the amount that is safe for a short period (like one hour, or one day) is higher than what we should be exposed to for a month or a year. For some contaminants there are no guidelines at all.

In this study, indoor air, outdoor air and the air the volunteers were personally exposed to were all tested, and measured against available guidelines. Because the technology to measure personal exposure is new, there are currently no provincial or federal guidelines.

Comparison of SULPHUR DIOXIDE Levels

units: micrograms/cubic meter

PARAMETER	Fort McMurray Median	Lethbridge Median	Guideline/ Reference Level
Personal	0.87	0.21	N/A
Indoor	0.41	0.16	50 (long term) ¹ 1000 (5 min.)
Outdoor	1.6	1.1	157 (day) ²
Ambient Station	2.0	N/A	445 (hour) ³ 157 (day) 26 (year)

- **SULPHUR DIOXIDE:** The study showed that ambient (outdoor) exposures to sulphur dioxide were much lower than the provincial guideline – 1.6 micrograms per cubic metre of air compared to a provincial daily guideline of 157 micrograms per cubic metre.

The average personal exposure level for Fort McMurray residents was 0.87 micrograms per cubic meter of air, compared to the Lethbridge average of 0.21 micrograms per cubic meter of air. Although the level is higher in Fort McMurray, the exposure level in both communities is very small.

Comparison of NITROGEN DIOXIDE Levels

units: micrograms/cubic meter

PARAMETER	Fort McMurray Median	Lethbridge Median	Guideline/ Reference Level
Personal	15.9	17.7	N/A
Indoor	8.6	9.8	100 (long term) ¹ 480 (hour)
Outdoor	9.5	13.8	206 (day) ²
Ambient Station	10.8	N/A	394 (hour) ³ 206 (day) 56 (year)

- **NITROGEN DIOXIDE:** The median level of nitrogen dioxide at the ambient stations was 10.8 micrograms per cubic meter of ambient air compared to daily guidelines of 206.0 micrograms per cubic meter.

The average personal exposure level for Fort McMurray residents was 15.9 micrograms per cubic meter of air, compared to the Lethbridge average of 17.7 micrograms per cubic meter of air.

Comparison of OZONE Levels

units: micrograms/cubic meter

PARAMETER	Fort McMurray Median	Lethbridge Median	Guideline/ Reference Level
Personal	3.3	4.9	N/A
Indoor	2.4	2.4	240 (hour) ¹
Outdoor	39	57	N/A ²
Ambient Station	50	N/A	50 (day) ³

- **OZONE:** The median level of ozone recorded at the ambient stations was equal to the Alberta Environment guideline of 50 micrograms per cubic meter.

The average personal exposure level for Fort McMurray residents was 3.3 micrograms per cubic meter of air, compared to the Lethbridge average of 4.9 micrograms per cubic meter of air. For most participants, ozone exposure fell below detectable levels.

FOOTNOTES:

1. Health Canada 1989 Exposure Guidelines for Residential Indoor Air Quality:
A Report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health.
2. Alberta Environment Guidelines
3. Alberta Environment Guidelines

- Volatile Organic Compounds (VOCs): The study showed ambient VOC levels in Fort McMurray were low and comparable to levels reported for rural areas in Canada.

In addition, the levels of personal exposure of Fort McMurray residents to VOCs was 2.8 micrograms per cubic metre compared to Lethbridge residents who had exposure of 2.1 micrograms per cubic metre.

- Particulate Matter (dust, smoke, mould, pollen, and other airborne particles):

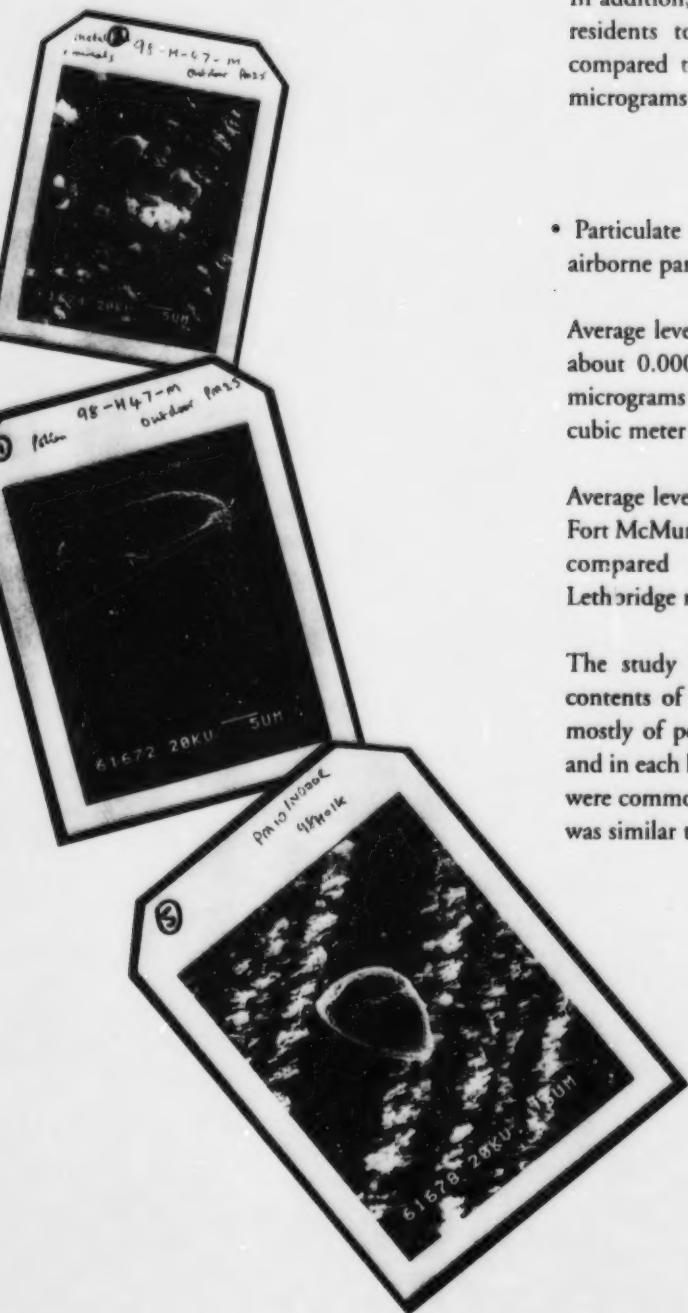
Average levels of PM_{2.5} (particles smaller than 2.5 microns or about 0.0001 inches) for Fort McMurray residents were 25 micrograms per cubic meter compared to 22.3 micrograms per cubic meter for Lethbridge residents.

Average levels of PM₁₀ (particles smaller than 10 microns) for Fort McMurray residents were 57.3 micrograms per cubic meter compared to 33.9 micrograms per cubic meter for Lethbridge residents.

The study also used electron microscopes to examine the contents of dust particles. Outdoors, particles were made up mostly of pollen; indoors, mould, hair and fibers dominated, and in each location, sand-like minerals (like silica and calcium) were common. The analysis of minerals in Fort McMurray's air was similar to other samples taken in rural Alberta.

"For the residents of Fort McMurray, this study shows that their exposure to airborne contaminants is very low, and within even the most stringent guidelines."

Dr. Stephan Gabos



RECOMMENDATIONS

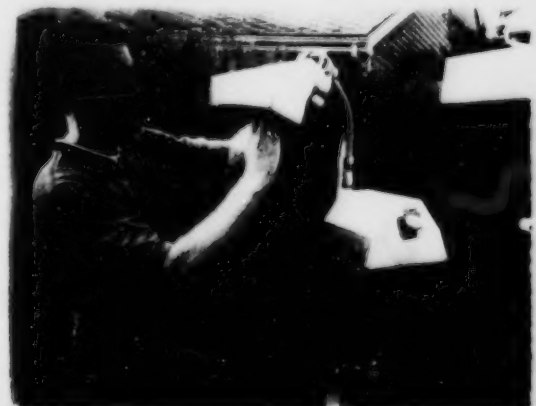
There are recommendations in the study that will be of interest to the community, air monitoring networks, governments, industry and others. The science team is recommending:

- Although this study did not find evidence of significantly elevated personal exposure to airborne contaminants from the oil sands industry, there should be on-going community monitoring of personal exposure levels to air contaminants to measure whether any of the contaminants produced by industrial development increase over time compared to the baseline established by this study,
- There should be continued emphasis on finding and using innovative testing technologies to measure personal exposure levels, and
- Similar community exposure studies should be conducted in other regions, comparing the results from Fort McMurray with these regions.

DID YOU KNOW?

In addition to the health information, the study also collected some interesting facts about the people in Fort McMurray. Did you know that:

- The average age of the volunteers in Fort McMurray was 40 – and 94% of the region's population is under 55.
- We are more likely to smoke – in the Northern Lights Health Region 33% smoke daily, compared to 25% nationally. Of the volunteers, 45% used to be daily smokers, while only 16% currently smoke.
- Activity levels are lower, and body mass is higher. Volunteers from Fort McMurray averaged 4.5 hours of physical activity a week, compared to 7.1 hours for the group from Lethbridge. As you might expect, 7% of the Fort McMurray participants were slightly overweight, and 44% had a body mass index over 27 (20-25 is healthy, 25-27 slightly overweight, and over 27 indicates an increased risk of health problems).



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- Website: www.health.gov.ab.ca



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HEALTH AND WELLNESS

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 **Northern Lights**
Regional Health Services

 **the Alberta Oil Sands Community
Exposure & Health Effects
Assessment Program**



SUMMARY REPORT

The Alberta Oil Sands Community Exposure And Health Effects Assessment Program

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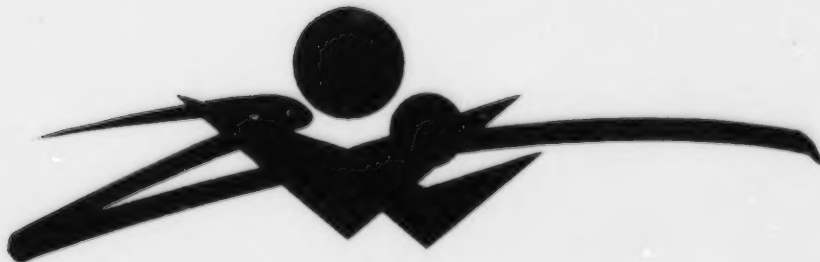
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Securing Canada's Energy Future

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**The Alberta Oil Sands Community Exposure and
Health Effects Assessment Program:**

Summary Report



May 2000



This report is one of a series of published documents:

Pilot Study, 1997
Summary Report, 2000
Methods Report, 2000
Technical Report, 2000

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1.0 Executive Summary

1.1 Objective

This report provides an overview of the Alberta Oil Sands Community Exposure and Health Effects Assessment Program Main Study. The report describes the population and personal distribution of exposure to airborne chemicals and particulates in the city of Fort McMurray. Using a personal exposure model, the relative contribution of various exposure sources and pathways to airborne chemicals is estimated and associations between exposure to airborne chemicals and human health effects are described.

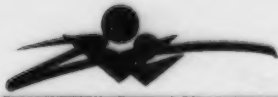
1.2 Methodology and Analysis

The data used for the analysis was collected over an 18-month period (June 1997 to November 1998), using volunteers from the city of Fort McMurray. A small sample of volunteers was also recruited from the city of Lethbridge that served as a control community for the Fort McMurray sample. Data from the two communities was evaluated and, where applicable, additional comparisons were made to the scientific literature. The study collected a variety of measures for each participant, including personal, indoor, and outdoor levels of selected contaminants (sulfur dioxide, nitrogen dioxide, ozone, a group of volatile organic compounds, and particulate matter), measures of other sources of exposure, diet and health behaviors, and selected health outcomes.

1.3 Significant Findings

The study included an assessment of the local environment and the potential sources of the selected contaminants in the region. The analysis of the relative contribution of various exposure sources found that:

- Ambient concentrations were not a good predictor of personal exposures.
- The most important exposure source of nitrogen dioxide (NO_2) was identified as local sources. Influences from background and regional sources were not detected. The presence of indoor sources could not be confirmed.
- The most important exposure source of sulfur dioxide (SO_2) identified was local sources (urban emissions such as vehicle exhaust) followed by regional sources (such as oil sands activity). An influence from background sources and indoor sources was not detected.
- The most important exposure source for ozone (O_3) was background sources. Indoor, local, and regional influences that increase exposure were not detected.
- In terms of mass concentration, the most important exposure sources of particulate matter $2.5\mu\text{m}$ ($\text{PM}_{2.5}$) were personal activity and indoor sources. Influences from outdoor air (i.e., local, regional, and background sources) were not detected.
- In terms of PM character (composition), the study found a significant influence from the oil sands plants on the vanadium content of the $\text{PM}_{2.5}$. Local, background, and indoor sources did not influence vanadium composition.



Analysis of the individual measures of exposure indicated that:

- Indoor and outdoor levels were responsible for less than 5% of the variance in levels of personal exposure to PM_{10} . Important factors influencing variation in personal exposure did not exert effects through indoor and outdoor concentrations.
- Nitrogen dioxide levels were low compared to existing guidelines and were comparable to other similar studies.
- Sulfur dioxide indoor and ambient levels were very low compared to existing guidelines.
- Ozone indoor and personal levels were very low. Outdoor and ambient levels were an order of magnitude higher, which suggests that ambient measures are an inadequate measure of personal exposure. Personal levels were only 10% of outdoor levels and changes in outdoor concentrations accounted for less than 5% of the variation in personal exposures.
- Indoor concentrations were the predominant factor affecting personal exposure to VOCs. Other factors were of only minor relative importance, which suggests that exposure to VOCs was predominantly from sources affecting indoor levels.
- $PM_{2.5}$ outdoor concentrations were not important as either a driver or a pathway of personal exposure.
- PM_{10} ambient concentrations were not a good predictor of personal exposures.

An exposure model was developed as an attempt to describe the effects of the variability of a series of nine groups of factors on variation in personal exposure. These nine factors are: 1) gender; 2) housing; 3) job status; 4) smoking; 5) seasonal effects; 6) time activity; 7) exposures; 8) indoor levels; and 9) outdoor levels.

- Variability across time activity measures accounted for over one-third of the variation in personal NO_2 exposure described by the model; variation in outdoor and indoor levels each accounted for roughly one-quarter of the variation. The amount of time spent indoors at locations other than home (i.e., work) was identified as important. Seasonal variation had a significant influence on personal levels.
- Overall, variations in indoor levels across houses (under the influence of outdoor levels) and temporal variability of outdoor levels accounted for roughly three-quarters of the variation in personal SO_2 exposure explained by the model. Outdoor levels, indoor levels under the influence of outdoor levels, and time activity were also important factors affecting personal exposure.
- The majority of variation in personal O_3 exposure described by the model was due to indoor concentrations that were heavily influenced by seasonal effects (lower concentrations in winter) and influenced to a lesser degree by outdoor concentrations. Overall, indoor levels explained over 30% and outdoor levels explained less than 5% of the variance in personal O_3 levels. Seasonal variation was an important effect that appears to impact personal exposure almost independently of outdoor concentrations (i.e., by affecting time activity, specific exposures, and indoor concentration). It cannot be over emphasized that outdoor concentrations were not a good surrogate measure of personal exposures in this study. Personal levels were only 10% of outdoor levels and changes in outdoor concentrations accounted for less than 5% of the variation in personal exposures.
- Indoor concentrations were the predominant factor affecting personal VOCs exposure; the other factors were of only minor relative importance. Outdoor concentrations did not have a significant



direct effect on personal exposure but had a small indirect effect through indoor air accounting for about 2% of the variance in personal exposure.

- Additional investigations during the study located high VOCs concentrations in some house garages and at gasoline service stations.
- Time activity, smoking, and job status were important factors affecting $PM_{2.5}$ exposures, accounting for roughly two-thirds of the variation explained by the model. Indoor concentrations had an important impact on personal exposures both directly and as a pathway through which other factors act (about 12%). Outdoor concentrations were not important as either a driver or a pathway of personal exposure.
- Smoking characteristics, job status, and specific exposures were important factors affecting PM_{10} personal exposures, accounting for roughly three-quarters of the variation explained by the model. Indoor and outdoor levels were responsible for less than 5% of the variance in personal exposure to PM_{10} . Important factors influencing variation in personal exposure did not exert effects through indoor and outdoor concentrations. Ambient concentrations were not a good predictor of personal exposures.

In addition to measuring personal exposure and potential sources for those exposures, the study collected a variety of indicators of health status. Measures of lifestyle behaviours, previous diagnoses and contacts with the health care system were recorded, in addition to objective measures of lung function, neurocognitive functioning, and biomarkers of exposure and effect. The study found that:

- There were no differences found in nutritional intake between Fort McMurray and Lethbridge. The average body mass index (BMI) for the two sample populations was higher than the estimated Canadian average, indicating a higher level of obesity in both sample populations, and the Fort McMurray participants were significantly less active compared to the Lethbridge participants.
- No statistically significant differences between the samples on any of the self-reported health questionnaires were identified, and previous diagnoses were very similar in the two samples.
- The most common diagnoses in Fort McMurray included: allergies (46%) and back problems (22.3%). There was no difference in overall illness between people who participated in the study and those who did not.
- Nicotine levels were found to be independently related to the amount participants smoked, whether participants allowed smoking in the car, and to the number of test days participants were exposed to smoke.
- Very few individuals had appreciable urine levels of biomarkers for exposure to ethylbenzene or xylene. Biomarkers for benzene and toluene were found (muconic acid and hippuric acid, respectively), however, because personal exposure levels were all very low, the relationship between personal exposure and urine biomarkers was not strong enough to be statistically significant.
- Arsenic levels in the serum and urine of Fort McMurray and Lethbridge participants reflected normal background concentrations.
- The percentage of samples that were positive for autoantibodies (a biomarker of effect) are comparable to findings in the literature for normal, healthy populations, and there are no significant differences between the Fort McMurray and Lethbridge samples.



- The Fort McMurray and Lethbridge samples were within referent ranges for overall lung function and no statistically significant differences were found between groups.
- No statistically significant differences in neurocognitive functioning were found between the samples or in comparison to reference populations, except that the participants in Fort McMurray performed significantly better on a test of motor speed (finger tapping).

1.4 Recommendations

1. Continue the ongoing monitoring of personal exposure levels to air contaminants with special emphasis on those unique to oil sands activities.

Although this study did not find evidence of significantly elevated personal exposure to airborne contaminants attributable to oil sands activities in the general population, there is evidence to suggest that industrial activities may generate specific contaminants that could be used as indicators for anthropogenic activities. Vanadium measured in the outdoor PM_{2.5} samples may be one example. A long-term monitoring program is recommended that would monitor personal exposure to these and other compounds, in order to detect any changes over time (e.g., increases) in the baseline level of contaminants associated with oil sands development.

2. Participate in the implementation of an organized approach to community exposure assessment in the province in support of long-term comparisons with other areas across the province.

Strategic information gathering on community exposure and health across the province is key to evidence based decision making, on managing health risks, and the development of health promotion, disease prevention, and exposure control strategies. Such information is also important to respond to public concerns about air contaminants and health and for the development of health based air quality guidelines at a local, regional, and provincial level. Therefore, in collaboration with other agencies and organizations such as Alberta Health and Wellness, regional health authorities, the Clean Air Strategic Alliance, and Alberta Environment, a coordinated system should be developed for the ongoing collection, analysis, and interpretation of air quality and health information. Such a system should be sustainable, cost-efficient, and should build on already existing resources without adding significant new costs.

3. Adopt and promote the use of innovative methods and technologies such as personal exposure monitoring to further our understanding of the relationship between air quality and human health.

The results of this study indicate that the ambient concentration of contaminants measured at monitoring stations is not a good predictor of human exposure (i.e., personal exposure). In the study of health and air quality and in the development of human health-based air quality guidelines, it is important to go beyond traditional emission inventories and ambient air quality monitoring. Personal exposure monitoring is a method that can complement existing methods.



2.0 Introduction

The Alberta Oil Sands Community Exposure and Health Effects Assessment Program was established following public hearings conducted by the Alberta Energy and Utilities Board in relation to Syncrude's Mildred Lake Development Project (1994). The primary goal of the development of this program was to establish possible links between air quality and human health outcomes. Human health concerns related to air quality were raised by various participants including aboriginal groups, environmental associations, and Alberta Health and Wellness. The Alberta Energy and Utilities Board views and recommendations of the human health issue were:

"The Board acknowledges the concerns of many of the interveners that atmospheric emissions from the oil sands plants are impacting on the health of the region's population. The Board believes that there is an obligation on industry to address this issue as effectively and rapidly as possible. The Board also acknowledges Syncrude's commitment to support and participate in a regional health study that is broadly based and involves all stakeholders. The Board notes, however, that concerns about the health effects from atmospheric emissions have, despite a number of efforts, continued to exist in the oil sands region as well as other areas of the province. The Board does not support a health study carried out simply for its own sake and expects any health study undertaken in the region to be meaningful, with terms of reference sufficiently broad to demonstrate both short and long term effects."

The Alberta Oil Sands Community Exposure and Health Effects Assessment Program was developed to ensure that a long-term, systematic approach to data gathering was implemented that would improve our knowledge about the link between the environment and human health.

The Board recommendations included an evaluation of the impact of emissions on all residents of the region, however the Fort McKay First Nation determined that it would be in their best interests to independently conduct a study of exposure and human health effects in that community. This component study was managed by the Fort McKay First Nation and direction was provided by a separate Steering Committee. The Fort McKay study was not vetted by the Alberta Oil Sands Community Exposure and Health Effects Assessment Program's Science Advisory Committee, nor its Science Team.

The Alberta Oil Sands Community Exposure and Health Effects Assessment Program combines two broad concepts in an integrated population-based environmental health framework: (1) the direct measurement of personal and population exposure to environmental factors, and (2) the epidemiologic surveillance of health outcomes in the population.

Several countries as well as the World Health Organization (WHO) are implementing exposure and health effects assessment approaches to address human health concerns related to environmental and other (e.g., occupational) factors. The Alberta Oil Sands Community Exposure and Health Effects Assessment Program is modeled after the USEPA TEAM approach.¹ The program was designed with a phased approach to implementation:

1. The first or preliminary phase of the program was designed to develop the methodology to be used in the main investigation and to address the technical, laboratory, and logistical aspects of the program. This was accomplished by developing an appropriate sampling strategy, exposure assessment field methodology, analytical laboratory testing, health effects assessment, and data analysis capabilities. This component was referred to as the *Pilot Study*.²



2. The second phase of the program, or *Main Study*, was intended to produce baseline population exposure and health outcome data. This was accomplished through a population exposure assessment conducted in conjunction with a population health assessment, and is the basis for this report.
3. The third or *Monitoring* phase of the program will consist of ongoing surveillance of exposure and health effects in the target population. This will be accomplished by periodic measurement of exposure linked to a population health status assessment.

3.0 Main Study Objectives

The Main Study of the Alberta Oil Sands Community Exposure and Health Effects Assessment Program had three main objectives:

1. Describe the population and personal distribution of exposure to airborne chemicals and particulates:
 - estimate the population distribution of selected airborne chemicals and particulates;
 - estimate the seasonal variation of exposure and;
 - characterize the personal variation of exposure as a function of individual activity patterns.
2. Quantify the relative contribution of various exposure sources and pathways to airborne chemicals:
 - quantify the relative contribution of outdoor and indoor air to the total exposure.
3. Describe associations between exposure to airborne chemicals and human health effects:
 - analyze occurrence relationships between selected exposures, biomarkers, and health outcomes.



4.0 Study Method and Protocol

4.1 Components of the Main Study

The Alberta Oil Sands Community Exposure and Health Effects Assessment Program was modeled after the USEPA TEAM approach.³ As discussed previously, the TEAM approach is based on four fundamental characteristics: direct measurement of all routes of exposure (breathing, ingestion, and skin contact), direct measurement of biomarkers, daily logs of a participant's activities and a representative probability sample. The study was designed to assess exposure and associated health effects by direct measurement of personal exposure, direct measurement of biomarkers, and daily logs of a participant's activities. The study did not use a representative probability sample, for two major reasons:

- 1) the high level of commitment required from participants; and
- 2) the high cost of administering a complex sampling design.

The science team determined that the high level of commitment required from potential participants would result in a biased sample, regardless of the recruitment method. Furthermore, the high cost of administering a complex sampling design was not considered to be offset by an improvement in the selection bias. Consequently, participants were recruited on a volunteer basis. The *Methods Report* provides a more detailed description of the various components in the study, including the methods, protocols, and validation studies. Please refer to this document for further detail.

The contaminants identified for personal exposure measurement for the Alberta Oil Sands Community Exposure and Health Effects Assessment Program were sulphur dioxide, nitrogen dioxide, ozone, volatile organic compounds and particulates. The final list of contaminants were identified using three criteria:

- 1) the local priority contaminants of concern;
- 2) national initiatives; and
- 3) the availability of technology to measure the contaminants.

The local community identified a number of priority contaminants, and these were highlighted during the public hearings conducted by the Alberta Energy and Utilities Board in relation to Syncrude's Mildred Lake Development Project (1994). Human health concerns related to air quality were raised by various participants including aboriginal groups, environmental associations, and Alberta Health and Wellness.

National initiatives have also identified these contaminants as a priority, as evidenced by the Canada-wide standards initiative on particulate matter and ozone, among other contaminants.

Finally, the availability of appropriate technology was a key defining factor in the final selection. Personal samplers for ozone and particulate matter were commercially available, but samplers for SO₂ and NO₂ had to be developed and tested during the pilot study. Commercially available VOC samplers were deployed during the pilot study and analyzed for a wide range of contaminants; the final selection of VOCs analyzed for the main study included all VOCs for which measurable quantities were identified during the pilot study.

The selection of biomarkers for the Alberta Oil Sands Community Exposure and Health Effects Assessment Program was based on a number of factors, including the ability of the laboratory to measure low levels of relevant biological markers, the most appropriate media for measuring the markers, and the burden placed on each volunteer. The final set of biological measures of exposure included: trace metals such as arsenic, cadmium, lead, and uranium; nicotine; and metabolites of the BTEX compounds



(benzene, toluene, ethylbenzene, m-, p-, and o-xylene). Although there are several methods of measuring benzene exposure in biological media, the most appropriate measure of low level exposure to benzene from environmental sources is urinary muconic acid.⁴ Studies have shown that urinary muconic acid is the most sensitive measure available to detect environmental exposures of less than 1 mg/m³.⁵ Similarly, urinary mandelic acid, hippuric acid, 2-, and 3-, 4-methylhippuric acids are indicative of exposure to ethylbenzene, toluene, and o- and m-xylene, respectively. Measures of serum levels of nicotine were included to identify the contribution from tobacco smoke to serum levels of both trace metals and B-TEX compounds.

The biological measures of effect included in the study included: autoantibody activity, a neurocognitive assessment, and a respiratory health assessment, including a respiratory health history survey and a spirometry assessment.

Increases in antinuclear autoantibodies result from a reaction by the immune system to external stressors. Comparison of prevalence with reference populations can be used to demonstrate differences in exposure and response. In addition, it is important to estimate the impact on human health from natural sources such as pollen and dust, to determine the relative impact from oil sands activity.

Neurocognitive impairments have been associated with exposure to a variety of contaminants, both through high volume occupational exposure and low-level environmental exposure. Neurobehavioral tests have been demonstrated to be sensitive to minute changes in neurocognitive functioning resulting from exposure to contaminants such as lead, mercury, aluminum, and volatile organic compounds. Organic solvents also pose a threat to the central nervous system because of their lipophilic characteristics. Short-term low-level exposure has been linked with a pre-narcotic reversible effect of psychomotor slowing or vigilance decrement.⁶ Other studies have shown a pre-narcotic state of central nervous system depression, characterized by behavioral dysfunction.⁷ Further evidence of the detrimental health effects of organic solvents have demonstrated that heavy and long term exposure situations can induce a chronic, partially irreversible encephalopathy, with an excess of neuropsychiatric complaints.^{8,9} Volatile organic compounds (VOC) can have a similar impact on the central nervous system. Symptom questionnaires and rating scales have produced consistent evidence of sensory irritation or discomfort resulting from exposure to low-level VOC mixtures.¹⁰ Among the wide range of VOCs, toluene is the best known neurotoxicant. Accidental occupational exposure¹¹ and controlled exposure experiments^{12,13} have demonstrated its adverse effects on balance, cognitive function, and colour vision. Moreover, toluene toxicity can be further increased with the simultaneous exposure of methyl ethyl ketone.

The respiratory system is naturally a major site of exposure to airborne contaminants. The effects of exposure to airborne contaminants on the respiratory system may range from mild, acute, and reversible, to severe, chronic, and permanent. Epidemiological studies have shown increased respiratory symptoms (sneezing, cough, chest pain, wheezing) and asthma medication use;¹⁴ hospital admissions for respiratory illness;¹⁵ cardiovascular mortality;¹⁶ and all-cause mortality¹⁷ associated with increased concentrations of some airborne contaminants. Acute effects of exposure to such contaminants as ozone, nitrogen dioxide, sulphur dioxide, inhalable suspended particles, and volatile organic compounds, may include irritation of the respiratory tract, resulting in coughing, sneezing, chest pain, wheezing, etc. and the exacerbation of asthma symptoms; higher concentrations may cause lung edema. In high concentrations, sulphur dioxide can even cause death due to spasm of the larynx and respiratory arrest.¹⁸ Chronic exposure to these contaminants may cause structural alterations in the respiratory epithelium that compromise oxygen absorption and lung elasticity, reduce the ability of ciliated cells to clear mucus from the lungs, leading to increased susceptibility to infection, and may contribute to tumor formation.¹⁹ Hummerfelt argued that occupational exposure to sulphur dioxide and metal fumes results in an accelerated decline in forced expiratory volume in 1 second (FEV₁).²⁰

Summary Report



Measuring the extent of damage due to exposure to airborne contaminants can be problematic. Spirometric measurements such as FVC or FEV₁ produce consistent results, but may not be sensitive enough to detect damage to the smaller airways, which are the primary site of attack by airborne contaminants. On the other hand, tests of small airway function, such as the FEF_{25%-75%}, are more sensitive, but show large within-individual variation, decreasing the reliability of results.²¹ The measure of choice in this case was FEF_{25%-75%} because it is sensitive enough to detect obstruction in the small airways, and its higher variability makes it more useful in the comparison of data from large populations.²²

In addition to the direct measures of exposure and the measurement of biological markers of exposure and effect, the study instruments also included a time-activity diary that required participants to record daily activities that might have an effect on exposure.

The Main Study collected and utilized a very broad range of human health and exposure data sources. Figure 1 provides a pictorial description of some of these sources of data. Table 1 provides a more extensive list of data sources for the project, grouping them into various components and providing a purpose for collecting each source of data. The *Methods Report* provides a detailed description of the various components in the study, including the methods, protocols, and validation studies. Please refer to this document for further detail.

Figure 1 Components of the Main Study

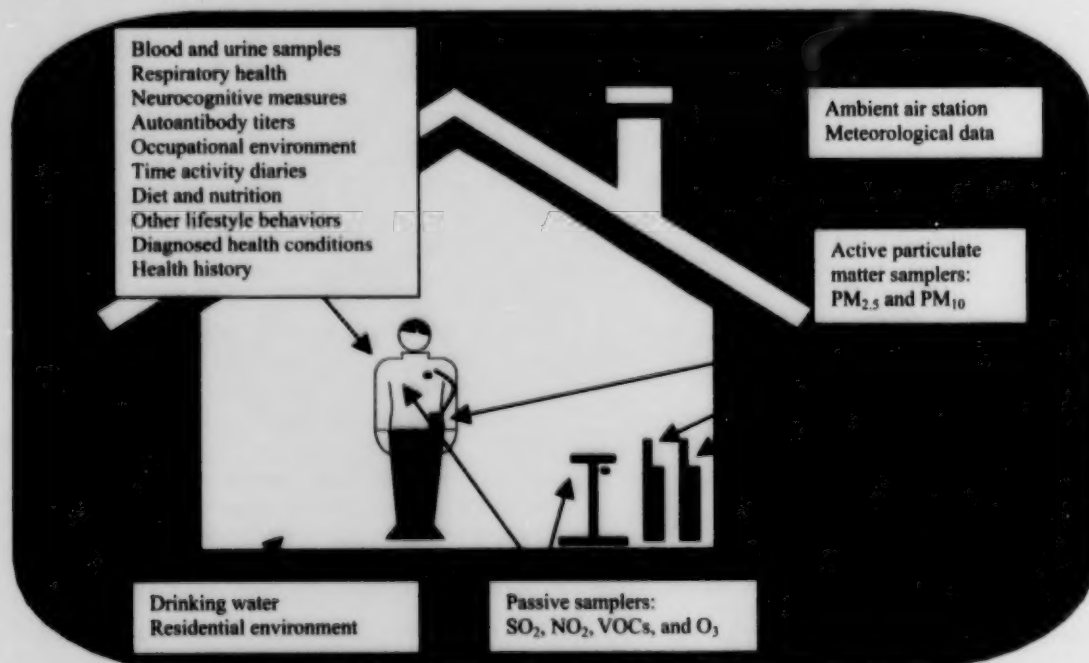




Table 1: Components of the Main Study

Component	Media or Source of Data	Purpose
Characteristics of the Sample	Vital Statistics Other Demographics	General information was collected to help characterize the samples and populations.
	Lifestyle behaviors	Questionnaires identified individual smoking habits, body mass index, nutritional intake, and physical activity levels.
	Drinking water	Routine chemistry and trace metals were measured in a sample of the drinking water used by the household.
	Time Activity Diary	The time activity diary identified potential routes of exposure in daily activities.
Exposure Measurement	Personal Exposure Monitors Passive samplers Particulate samplers	Exposure measurement identified the actual exposure levels of each participant during a regular day, using personal, indoor, and outdoor air monitors. A sub-sample of participants was asked to provide exposure measures for particulate matter.
	Electron microscopy	Particulate matter samplers were analyzed for the presence and type of organic, mineral, and metal particles.
	Household sources Work sources Dietary exposure	A questionnaire was used to identify potential sources in the home and work environments, and identification of potential dietary sources of exposure.
Biomarkers of Exposure	Blood	Analysis included cotinine (a metabolite of nicotine) and a variety of heavy metal compounds including arsenic, selenium, lead, vanadium, and cadmium.
	Urine	Analysis included metabolites of the BTEX compounds benzene, toluene, ethylbenzene, m-, p-xylene, and o-xylene) and a variety of heavy metal compounds such as arsenic, selenium, lead, vanadium, and cadmium.
Biomarkers of Effect	Autoantibodies	Analysis included immunofluorescence microscopy to detect autoantibodies, which indicate elevated immune system reaction.
	Lung Function	Spirometry was used to measure the individual's lung capacity and volume during the exposure-monitoring period.
	Neurocognitive measurement	Computerized neurocognitive tests and the completion of other activities were used to determine the possible impact of chronic exposure on neurocognitive functioning.
Measures of Health	Questionnaires	Questionnaires identified general, occupational, emotional, and psychological health.
		A questionnaire identified previously diagnosed health problems.
Exposure Sources	WBEA ambient station data	Quantify relative contribution of local emission sources to exposure for various contaminants.
	Exposure measurements	



4.2 Recruitment of Volunteers

A sampling pool of volunteers was recruited from the community through the use of local newspaper, radio, and television advertisements, as well as some general phone solicitation and staff recruitment from the major employers. All participants were required to be 18 years of age and either temporary or permanent residents of the town of Fort McMurray, Alberta.

All participants were required to take part in a 1-2 hour interview at the study office. To meet the requirements of the air-sampling component of the study, volunteers had to be available for five consecutive evenings, beginning on the day of their initial appointment.

One participant was added to the study each day. This method maintained a steady and manageable workload for the field study teams, and ensured that an equal number of participants would be assessed in each season of the year.

The same approach of volunteer recruitment was used for the control community of Lethbridge, Alberta.

5.0 Context

5.1 Alberta

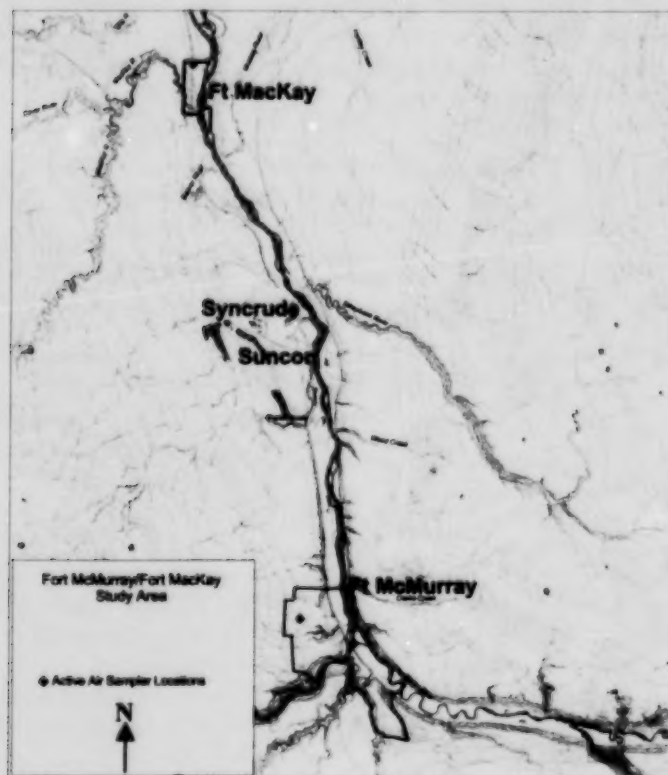
The province of Alberta is located in the prairies of western Canada. The Rocky Mountains and the province of British Columbia border Alberta to the west while the province of Saskatchewan is to the east. The state of Montana lies south of the Canada-U.S.A. international border and to the north are the Northwest Territories. The area of the province is 661,190km² (255,291mi²) with a population of 2,696,826. The population is highly concentrated in the major urban centers, such as Alberta's capital, Edmonton, and Alberta's largest city, Calgary, while the rural areas, especially in northern Alberta are sparsely populated. Alberta's major industries include forestry, oil and gas, agriculture, livestock management, and tourism.

5.2 Fort McMurray

As shown in Figure 2, Fort McMurray is situated within the Regional Municipality of Wood Buffalo in northeast Alberta, Canada. The site of the world's largest known oil sands deposits, Wood Buffalo is over 67,164km² (25,933mi²) and has an estimated 42,000 residents in 11 communities. Fort McMurray is the largest community with a population of 36,400 (March, 1999 City Census). The nearest metropolitan centre, Edmonton, is located 450km (280 miles) southwest of Fort McMurray, primarily linked by paved, two-lane Highway 63.



Figure 2: Map of Fort McMurray, Fort McKay, Suncor, and Syncrude



5.2.1 The Oil Sands Industry

The oil sands are very different from conventional oil and natural gas deposits. The oil sands are a mixture of bitumen (the thick black raw material extracted from the oil sands), sand, water, and clay. The major challenge in developing oil sands is separating the bitumen from the sand, water, clay, and carbon. Once separated, the bitumen is upgraded into high-quality oil called “synthetic crude”.

Oil sands and oil shale deposits are found all over the world. There are 16 major oil sands deposits, the largest of which is the Athabasca Oil Sands. There are also major deposits on Melville Island in the Canadian Arctic and three other smaller deposits in northern Alberta: the Peace River, Wabasca, and Cold Lake deposits. Figure 3 shows the location of the Alberta oil sands deposits. These four deposits cover an area of 199,430km² (46,113mi²). The Athabasca Oil Sands alone covers an area of more than 42,000km² (16,216mi²) and contains about 300 billion recoverable barrels of bitumen. In comparison, the Athabasca Oil Sands contain more oil than all the known reserves in Saudi Arabia and represents a third of the world’s known petroleum resources.



Figure 3: Oil Sands Deposits in Alberta



With the advancement of technology, the economic viability of oil sands development has increased. Full-scale development of the oil sands in the Fort McMurray region began when Suncor and Syncrude started operations in the 1960's and 70's. Fort McMurray has experienced tremendous growth and opportunity in the last three decades due to the abundance of natural resources in the area, including oil, gas, and forestry. The main industry is oil sands extraction and upgrading at Syncrude Canada, 44km (27 miles) north of the townsite, and Suncor Energy, 34km (21 miles) north of the townsite. The locations of these two industries in relation to Fort McMurray are shown in Figure 2. Combined, these two major industries employ about 7,000 people or approximately one-third of the labor force in the community and immediate surrounding area, while providing about 20% of Canada's energy needs. In addition to Syncrude Canada and Suncor Energy, there are a number of other oil extraction plants that also have employees living in the community. The gas industry has also played an increasingly important role in this region during the past several years. There are approximately 15 gas companies operating in the



region. Employment in the forestry sector is growing with the development of the Athabasca Pulp and Paper Mill (ALPAC) and general development of the forestry sector across northeast Alberta.

Syncrude Canada and Suncor Energy are currently in the process of expanding their industries. Syncrude Canada has construction underway on three major projects simultaneously: the second train in the North Mine area, the first train at Aurora, and the second phase of the Upgrader Debottleneck. All of these projects will be completed and commissioned by July 1, 2000. This will lead to an additional 15 million barrels of Syncrude Sweet Blend a year, bringing a projected total of 94 million barrels produced by 2001. Meanwhile, Suncor Energy has designed Project Millennium. The first phase of the project, called the Production Enhancement Phase (PEP), is designed to improve processes and increase plant capacity to reach 135,000 barrels per day by the year 2001. The second phase calls for further development of the Steepbank Mine, expansion of the extraction and upgrading plants, and increased requirements for steam, water, and electricity. The projected end result would be to expand production to 220,000 barrels of oil per day by 2002, doubling current production.

There are many other industries in the Fort McMurray region. Gulf Canada Resources Ltd. is investing in a pilot project in the Surmount area near Fort McMurray. Gulf, which owns or manages a 20.77% stake in the Syncrude plant, is planning to develop a commercial plant at Surmount. In 1997, Shell Canada Ltd. announced plans for a new major oil sands surface mine and extraction plant, located about 70km (43 miles) north of Fort McMurray. The proposed Muskeg River Mine will produce up to 150,000 barrels per day of bitumen starting in 2002. It will be linked to a new bitumen upgrader at Shell's Scotford Refinery near Fort Saskatchewan, Alberta, by the proposed 496km (308 miles) Corridor Pipeline. Koch Canada Ltd. has a 78% interest in the proposed 90,000 barrels per day Fort Hills bitumen mine project. Koch is expecting a significant increase in its workforce in the next few years. First Oil from the Fort Hills mine project is anticipated in 2005. Mobil Oil Canada plans to develop an oil sands mine, extraction facility, and related infrastructure. The mine will be designed to produce an estimated 130,000 barrels a day of bitumen and will be built and operated 70km (43 miles) north of Fort McMurray, Alberta. Projected construction is 2000 with First Oil anticipated in 2003.

5.3 Lethbridge

Participants were recruited from the city of Lethbridge to act as a control group for comparison with the main study sample from Fort McMurray. As shown by Figure 3, Lethbridge is situated in south-central Alberta. Lethbridge is 217km (134 miles) south of Calgary, 518km (321 miles) south of Edmonton, and 105km (65 miles) north of the Montana border. The population of Lethbridge is 68,712 (April, 1999 City Census). Table 2 shows other demographics for the city of Lethbridge with comparable data for Fort McMurray and Edmonton. Although Lethbridge is considerably larger than Fort McMurray, the two cities are considered medium-sized within the province of Alberta. Winter temperatures are colder in Fort McMurray due to its more northern proximity and also due to the warm chinooks that are characteristic in Lethbridge during the winter months.

Agriculture is the main industry of southern Alberta. It plays an important role in the Lethbridge's retail, wholesale, and service sectors. Service and trade industries comprise over one-half of all the occupations in Lethbridge, the largest employer being the Chinook Health Region.

Lethbridge served as an appropriate control community for Fort McMurray due to the contrast of industries between the two cities. The role of petroleum-based industries in and surrounding Lethbridge is minimal (oil sands mining is non-existent) compared to the crucial role of these industries in the Fort McMurray region. Both cities are relatively isolated from any major urbanized cities (i.e., Edmonton or Calgary) that may influence the quality of air and types and levels of environmental contaminants.



Table 2: Comparison of Fort McMurray, Lethbridge, and Edmonton^{23, 24, 25}

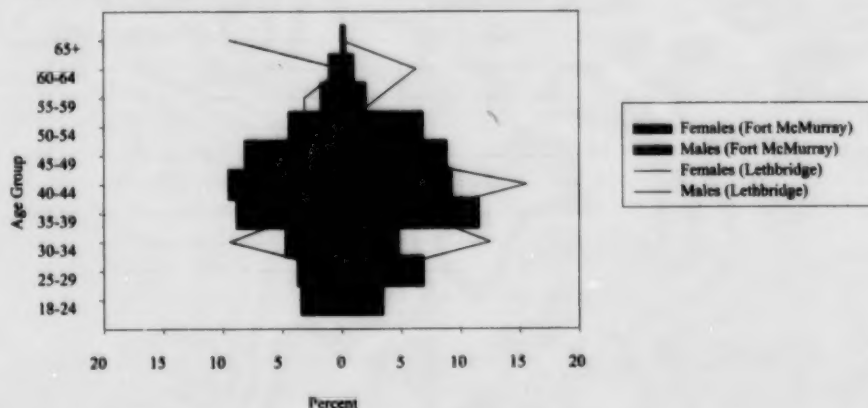
	Fort McMurray	Lethbridge	Edmonton
Population	36,400	68,712	616,306
Area	60.7km ² (15,000 acres)	127.1km ² (31,415 acres)	671km ² (165,811 acres)
Temperature	Jan.: -25.3°C (-13.5°F) July: 23.2°C (73.8°F)	Jan.: -14.2°C (6.4°F) July: 25.9°C (78.6°F)	Jan.: -17.0°C (1.4°F) July: 23.0°C (73.4°F)
Precipitation	Rain: 335mm (13.2") Snow: 172cm (67.7")	Rain: 263mm (10.4") Snow: 160cm (63.0")	Rain: 349mm (13.8") Snow: 130cm (51.2")
Elevation	369m (1211')	929m (3048')	668m (2192')

6.0 Characteristics of the Sample Populations

6.1 Age and Gender

The average age of the Fort McMurray sample population was 40 years (N = 300; SD = 10.05). The Lethbridge sample had a slightly higher average age of 44 years (N = 33; SD = 14.14). Figure 4 shows the age and gender distribution for the Fort McMurray and Lethbridge sample populations.

Figure 4: Age and Gender Distribution of Participants



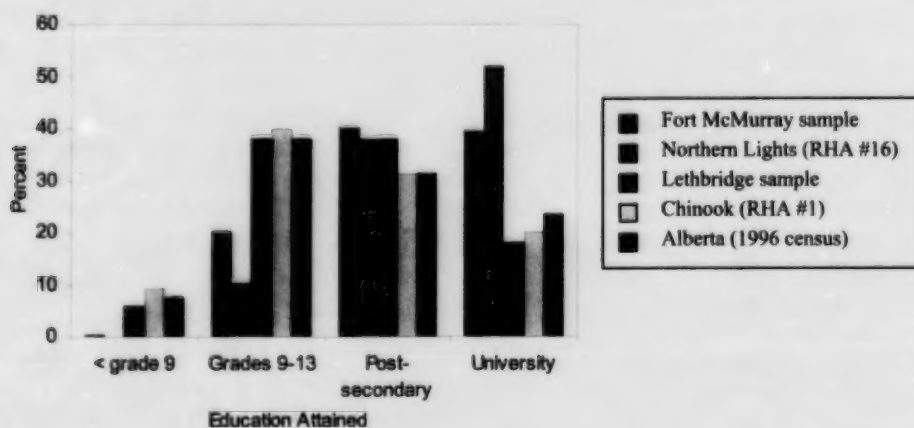
The *Technical Report* provides further detail of the age and gender structure of the two cities. The Fort McMurray sample chosen for this study reflected the population distribution of the townsite, according to the Alberta Health Care Insurance Plan Stakeholder Registry data for 1997/1998. The findings of the current study are consistent with a Health Needs Assessment conducted in December 1997 which stated that the population distribution and age structure of the Northern Lights Health Region (NLHR) is considerably different from the provincial average. It was found that approximately 94% of the region's population is under the age of 55 years, compared to only 83% for the province.²⁶



6.2 Education

Figure 5 displays the levels of education for the Fort McMurray and Lethbridge sample populations as well as for their respective Regional Health Authorities (RHAs) and for the province of Alberta. The average number of years of education was slightly lower in Fort McMurray participants compared to those from Lethbridge. For the Fort McMurray sample, the average years of education was 14.53 years ($N = 274$; $SD = 2.19$) compared to 14.90 years ($N = 29$; $SD = 2.18$) for the Lethbridge sample, a non-significant difference. Over half of the Lethbridge sample had completed at least one year of education at the university level compared to about 40% of the Fort McMurray sample. In comparison to the census data for their respective health regions and Alberta, both samples had higher levels of education.

Figure 5: Education of Participants



6.3 Language

English was indicated as the native language of 89.6% of the Fort McMurray sample population. In the 1996 census, 87.7% indicated their mother tongue as English, quite comparable to the Fort McMurray sample. The Lethbridge rate of 93.9% English was higher than the census rate of 83.1% for the Chinook Health Region.

6.4 Occupation

Almost half of the participants (42.2%) indicated that they were currently employed at one of the major oil sands industries in the Fort McMurray region (i.e., Syncrude Canada Ltd. or Suncor Energy). Table 3 displays the participants' primary employment status and whether this employment was full- or part-time.



Table 3: Primary Work or Employment Status

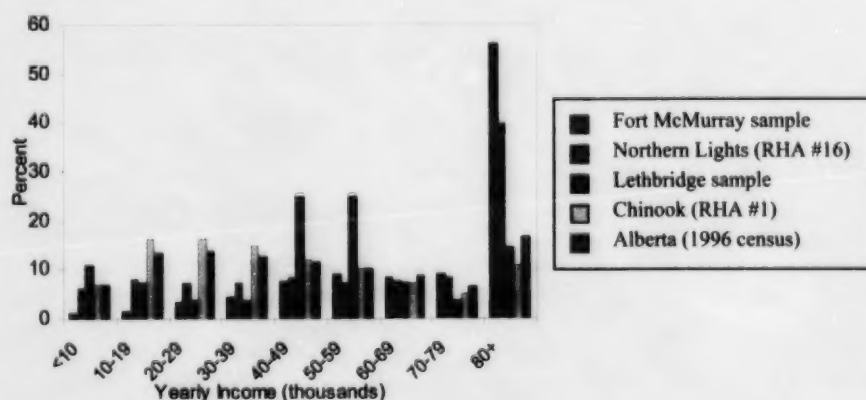
	Fort McMurray (N = 277)		Lethbridge (N = 30)	
Have a paid job outside of home	85.6%	84.4% FT 14.3% PT	63.3%	73.7% FT 26.3% PT
Self-employed in home	1.4%	25.0% FT 50.0% PT	3.3%	100% FT 0.0% PT
Student	1.4%	100% FT 0.0% PT	10.0%	100% FT 0.0% PT
Full-time homemaker	7.6%		0.0%	
Currently unemployed	1.1%		0.0%	
Retired or disabled	2.2%		23.3%	
Other	0.7%		0.0%	

Note: FT = Full-time, PT = Part-time

6.5 Income

Over half (56.0%) of the Fort McMurray participants indicated their annual household income to be \$80,000 or greater compared to only 14.3% of the Lethbridge participants. Figure 6 displays the distribution of household income for the Fort McMurray and Lethbridge sample populations as well as for their respective Regional Health Authorities (RHAs) and for the province of Alberta. As is confirmed by the Northern Lights Health Region (RHA #16) data, the percentage of households making at least \$80,000 annual income is about three times higher than both the Chinook Health Region (RHA #1) and Alberta as a whole. The RHA averages fall within the range of that found in both sample groups. With similar figures from the 1991 census, the Northern Lights Regional Health Needs Assessment stated that the annual household income in the NLHRA is the highest in Alberta and among the highest in Western Canada.²⁷ The socioeconomic status (SES) of each population was also examined. Nine percent (9%) of the Fort McMurray adult population and 23% of the Lethbridge adult population were defined as low SES and received a full subsidy from Alberta Health Care Insurance Plan and/or were receiving financial support from family and social services.

Figure 6: Distribution of Household Income





6.6 Smoking

Of the Fort McMurray sample, 44.8% and 46.7% of the Lethbridge sample, indicated they had smoked as much as one cigarette a day for as long as one year. Whether the participants currently smoked or not, both samples reported that when they did smoke, they smoked 11 to 20 cigarettes per day.

The majority of Fort McMurray (79.6%) and Lethbridge (82.6%) respondents indicated that they worked in a non-smoking environment; however, the average daily exposure to cigarette smoke (second-hand smoke) varied greatly across participants, from no exposure to as much as 900 minutes per day.

The Northern Lights Regional Health Needs Assessment found that smoking prevalence in the NLRHA is higher than the Canadian average.²⁸ The percentage of regional residents who smoked daily was 32.7% compared to the Canadian average of 25%. These figures are high in comparison to both sample populations where it was found that 15.8% of Fort McMurray participants and 18.2% of Lethbridge participants currently smoked.

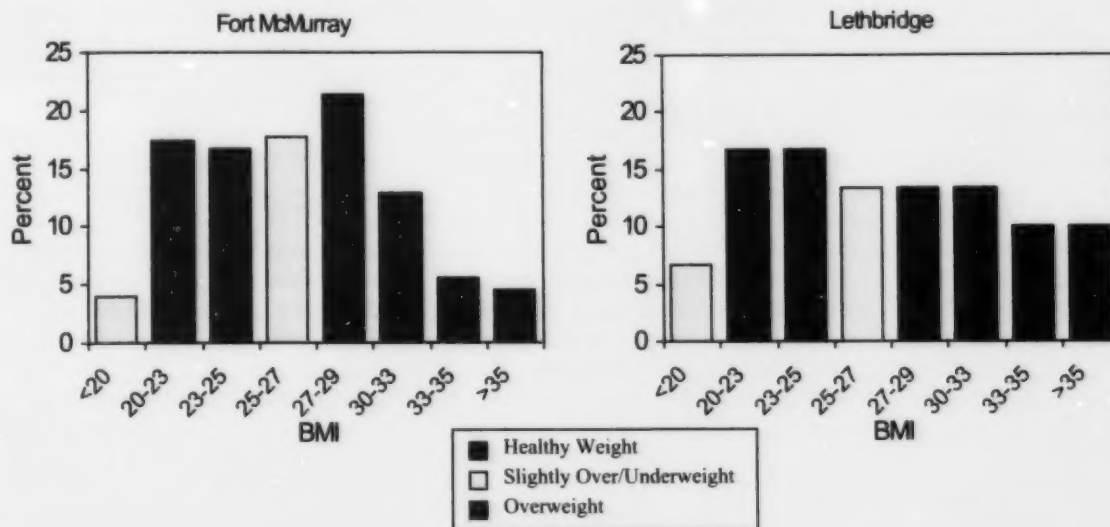
6.7 Body Mass Index

A body mass index (BMI) was calculated for each participant based on reported height and weight. The BMI is considered a valid measure of obesity because it is a simple convenient measure that correlates well with skinfold and body density measures and has been adopted in the *Canadian Guidelines for Health Weights*.²⁹ A BMI of less than 20 indicates that the individual is underweight for their height, and there may be some associated health problems. A BMI between 20 and 25 is considered a healthy range. A BMI of between 25 and 27 indicates that the individual is slightly overweight, which may lead to health problems for some people, while a BMI over 27 indicates an increased risk of health problems associated with weight.

Figure 7 shows the distribution of BMI for the two sample populations. The average BMI for the Fort McMurray participants was 27.06 and the average BMI for the Lethbridge participants was 27.47, not a large enough difference to be statistically significant. Seventeen percent (17%) of the Fort McMurray participants and 13% of the Lethbridge participants were slightly overweight (BMI of 25 to 27); 44% and 47% of the Fort McMurray and Lethbridge participants, respectively, had a BMI greater than 27. The estimated average BMI for the Canadian population is 25.4, lower than either of the study populations. Fewer study participants had a BMI in the lower or healthy range compared to the Canadian estimates. A larger percentage of study participants from both study communities had a BMI greater than 30 compared to the Canadian estimates.



Figure 7: Distribution of Body Mass Index



6.8 Nutritional Intake

Participants were asked about their usual dietary habits. There was no difference in nutritional intake between the participants in Fort McMurray and the participants in Lethbridge. Both groups indicated that they ate less than the recommended 5 to 12 servings of grain products each day, and ate the minimum number (5 to 10) of servings of fruits and vegetables each day. The average number of servings of milk products corresponded to the recommended number (2 to 3), and the number of servings of meat and alternatives also corresponded to the minimum number of servings recommended by the Canada Food Guide (2 to 3). Respondents indicated that they consumed an average of between 2 and 3 servings of sweets or other non-nutritious foods each day. The average number of cups of coffee, drinks of cola, and drinks of alcohol were the same in the two communities: people drank an average of two cups of coffee per day, and less than one drink per day of cola or alcohol.

Participants were asked to approximate the amount of liquid they drank per day. Fort McMurray and Lethbridge respondents consumed an average of 7 cups (1.75 L) per day.

6.9 Local Wild Food Sources

The frequency of consumption of local wild food sources was recorded because this can indicate whether there are other sources of contaminants or pathways of exposure that are unique to the local population. Eighty percent (80%) of the population in Fort McMurray and all Lethbridge participants indicated that they eat locally grown fruits and vegetables when available. Sixty-three percent (63%) of the Fort McMurray participants and 57% of the Lethbridge participants indicated that they ate local wild berries. Consumption of local wild game was not as common as consumption of wild fruits, although 32.5% of the sample in Fort McMurray stated that they ate local moose, and 24.5% stated they ate local deer. Grouse was the only other game animal consumed by a large portion of the Fort McMurray study population (12%). By comparison, only 17% of the Lethbridge participants indicated that they ate locally



caught wild meat of any kind. A number of participants in both cities indicated that they ate locally caught fish, although the most common fish consumed differed according to the city. Walleye was the most frequently mentioned fish in Fort McMurray (25%), whereas Lethbridge participants (23%) mentioned trout more frequently.

6.10 Sources of Drinking Water

Data was collected on characteristics of household drinking water and personal drinking water habits. All Fort McMurray respondents (N = 277) indicated their source of tap water as the city water treatment facility. Tap water was used for drinking and drink mixes by 84.4% (N = 275) of participants. When drinking water from the tap, 63.3% (N = 256) indicated that they run the water for a period of time before filling their glass and 27.7% indicated that they "sometimes" do. About one-third (32.1%; N = 274) of respondents indicated that they have a filter of some type that "purifies the water", most of which were the activated carbon type (e.g., Brita, Amway). Bottled water was used by 27.4% (N = 277) of respondents, and another 31.8% indicated "sometimes". Of those that used bottled water, 35% (N = 160) indicated they use it for all drinking, while others limited their use of bottled water to travelling (55%), at work or school (46.9%), cooking (2.5%), and other uses (8.8%).

6.10.1 Drinking Water Quality

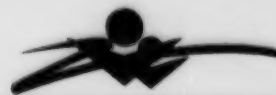
The field monitoring teams collected a sample of water from participants' kitchen taps for routine and trace metal analysis. There were a total of 237 routine analyses completed, 233 from Fort McMurray and four from Lethbridge. In addition, 238 trace metal analyses were completed, 234 from Fort McMurray and four from Lethbridge. Only four water samples were collected in Lethbridge to verify that the water quality was consistent with the city's water treatment plant; after this was established, it was determined that there was no longer a need to continue collecting water samples from Lethbridge participants.

Routine analysis of water consists of measuring the following properties: conductivity, total hardness, total dissolved solids, alkalinity, sodium, potassium, calcium, magnesium, iron, carbonate, bicarbonate, chloride, fluoride, nitrate and nitrite, and sulfate. None of the routine analysis measures exceeded maximum allowable concentration (MAC) limits. Please refer to the *Technical Report* for a more detailed discussion of this analysis.

The water was also analyzed for aluminum, antimony, arsenic, beryllium, boron, barium, cadmium, cobalt, chromium, copper, iron, lead, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, titanium, uranium, vanadium, and zinc. Silver, beryllium, thallium, and vanadium were not detectable at all in any of the 234 samples collected in Fort McMurray. None of the samples exceeded established MAC or aesthetic objectives (AO) except for two samples from Fort McMurray which slightly exceeded the AO for iron, and nine which exceeded the AO for manganese. Aesthetic objectives are far below the level at which health risks are present; they are established to prevent nuisance effects such as staining of laundry and plumbing, or bad tastes.

6.11 Physical Activity Level

The physical activity section of the Health Habits and Diet Survey assessed participants' involvement in a variety of physical activities. The Fort McMurray participants were significantly less active, on average, than the Lethbridge participants; the mean time spent in physical activity per week in Fort McMurray was 4.5 hours, compared to 7.1 hours per week in Lethbridge. Health Canada recommends at least 20-30 minutes of vigorous activity, or 60 minutes of light effort, every day, to maintain good health.³⁰ Of the

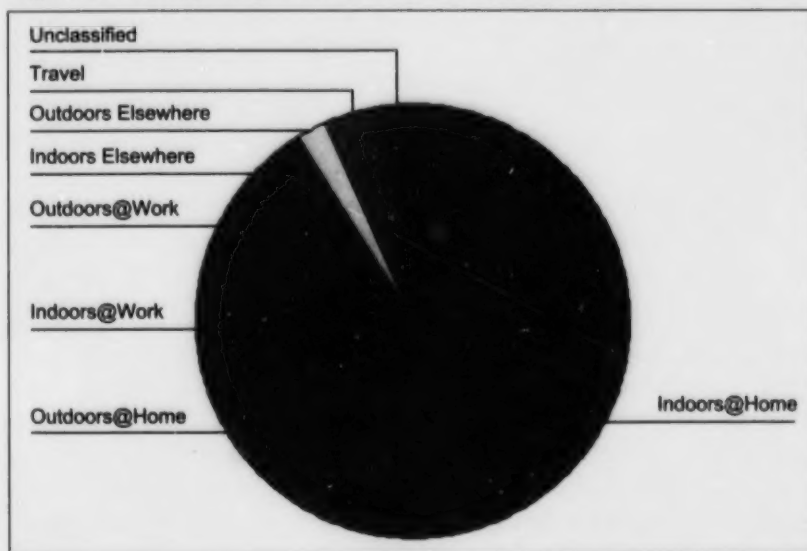


Lethbridge sample, 41.5%, and 56.3% of the Fort McMurray sample, exercised less than 3.5 hours per week. In comparison to 13.0% of Fort McMurray residents, none of the Lethbridge residents reported having engaged in no physical activities at all. In a Health Needs Assessment Survey conducted by the Northern Lights Regional Health Services, 22% of residents of the Fort McMurray area reported that they exercise either never or less than once a week;³¹ national statistics from Statistics Canada report the figure as 22.6% for all of Alberta. Even though a large proportion of the Lethbridge and Fort McMurray samples do not get enough exercise, they are still surpassing the provincial average.

6.12 Time Activity Diaries

Participants were asked to keep a time activity diary in which they recorded activities, the amount of time each of these activities encompassed, and specific exposures to certain chemicals for the four days in which their exposure to chemical concentrations was being monitored. The time activity diaries were coded into a set of times spent in general activities for each day, and into the presence or absence of a set of specific activities which might have led to unusual levels of exposure. Figure 8 shows the average levels of activities for the group as a whole.

Figure 8: Average Proportion of Time Activity in a Day



There are trade-off relationships among the relative mixes of general activities across different individuals. There was a clear relationship between time spent indoors at home, indoors at work, and travel such that as time spent indoors at work increases, travel time increases, and time spent indoors at home decreases. Similarly, with an increase in indoor activities elsewhere, travel time increases while time spent indoors at home and indoors at work decreases.

Gender and job status is also a major determinant of the relative activity mix. Table 4 shows that there is an interaction between job status and gender.

**Table 4: Gender and Job Status**

Full-time jobs	59.8% of females	(15.4% at Oil Sands Plants)
	96.1% of males	(74.4% at Oil Sands Plants)
Part-time jobs	22.7% of females	
	2.4% of males	

Job status is a major determinant of the amount of time spent indoors at home, indoors at work, and in travel.

Table 5 presents the proportion of days in which particular exposures (or activities increasing the likelihood of specific exposures) were noted in the analysis of the time activity diaries.

Table 5: Proportion of Days When Specific Exposures Indicated

	Female Full-time job		Male Full-time job		Total
	No	Yes	No	Yes	
Passive or active smoke	.236	.314	.250	.167	.233
Painting	.046	.045	.042	.043	.045
Gasoline	.068	.045	.042	.078	.064
House cleaning	.211	.119	.042	.054	.110
Burning	.118	.127	.000	.093	.108
Misc. Chemicals	.312	.343	.250	.148	.250

Further information is presented in the *Technical Report*. Analyses of the relationships between time activity and personal exposures are reported in a later section of this report.

7.0 Exposure Pathways

A number of chemical contaminants have well documented negative impacts on human health if they are present at sufficiently high levels. The Alberta Oil Sands Community Exposure and Health Effects Assessment Program examined levels of sulfur dioxide (SO₂), nitrogen dioxide (NO₂), ozone (O₃), a number of volatile organic compounds (VOCs), and particulate matter of two different sizes (PM_{2.5} and PM₁₀).

Data were collected on average daily air concentrations in personal, home indoor, home outdoor, and fixed site ambient environments. These concentrations were compared to the results from other empirical studies as well as to a variety of guidelines that have been established for human exposure.

Information on many factors that might impact personal exposure levels for these chemicals was also collected from study participants. This information was used to develop exposure models to describe the effects of variation in these factors on variation in personal exposure levels. The numerous factors were combined into nine variable groups based on similarities and were ordered in terms of their expected influence on personal exposure levels, from least direct to most direct as follows:



- 1) gender;
- 2) housing;
- 3) job status;
- 4) smoking;
- 5) seasonal effects;
- 6) time activity;
- 7) exposures;
- 8) outdoor levels; and
- 9) indoor levels

For example, the variable group "Time Activity" included separate variables measuring proportion of time spent inside the home, proportion of time spent outside at home, proportion of time spent inside at work, proportion of time spent outside at work, proportion of time engaged in other indoor activities, proportion of time engaged in other outdoor activities, and proportion of time spent travelling in a motorized vehicle. Similarly, the variable group "Housing Characteristics" included variables which distinguished between mobile homes, multiple housing units, and single family detached dwellings; indicated the age of the housing; and indicated whether the house used a heating method other than forced air, had a cold air return, or used urea formaldehyde insulation. Further information about the specific variables making up each of the variable groups can be found in the *Technical Report*.

Data analysis involved multi-step hierarchical regression analyses designed to isolate and quantify direct and indirect effects of the variable groups or factors on personal exposure levels. Direct effects are those in which variation in a factor is directly associated with variation in personal exposure when the effects of all other factors are held constant. Indirect effects are those which operate on other variables in the model (which in turn are directly associated with variations in personal exposure). For example, outdoor air levels may directly influence personal levels of a chemical, and indoor levels may also directly influence personal levels, but outdoor levels may also indirectly influence personal levels by influencing indoor levels (which in turn directly influence personal levels). There are a large number of ways in which a variable group or factor may have an indirect effect on personal levels.

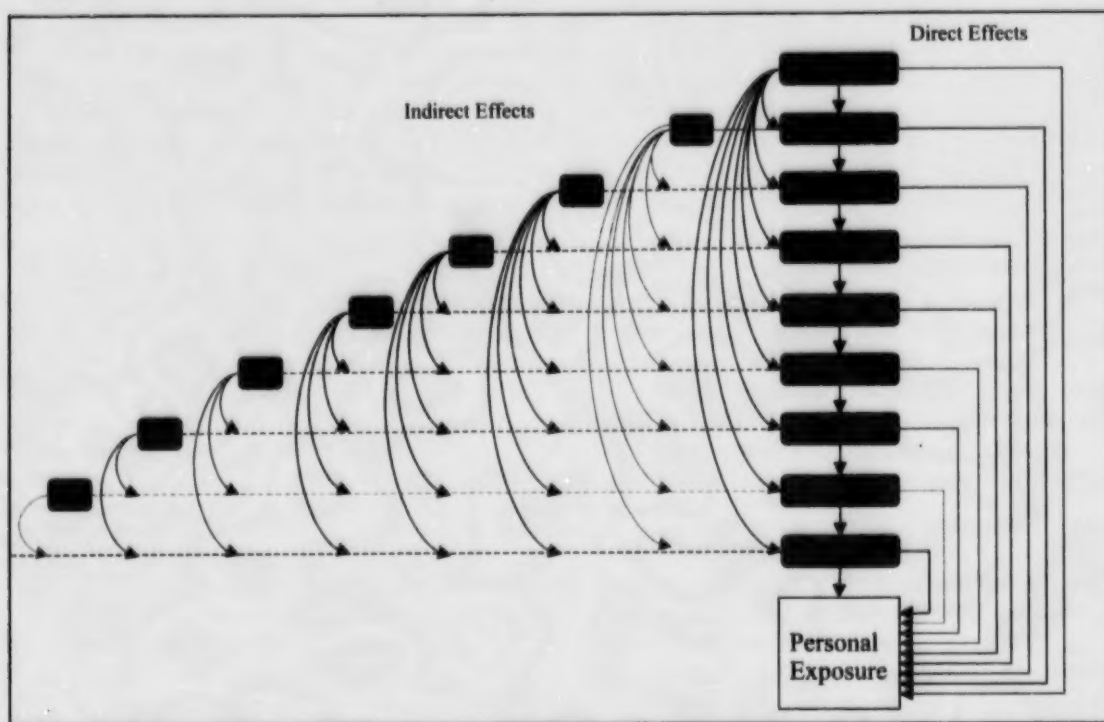
The analysis of each contaminant attempted to quantify the amount of the variability in personal exposure that could be attributed to variability in each factor. The traditional measure used for this purpose is a proportion of variance, R^2 , derived from the correlation, r , or multiple correlation, R , of the variable(s) to personal levels when the effects of including other variables in the model are taken into account. The measure R^2 will vary from 0.0 when there is no effect to 1.0 when personal levels can be perfectly predicted by variation in some other factor or factors. In the simplest case, where only two variables are being considered, a scatterplot of these two variables can be presented which shows the degree of relationship between them. It is usually accompanied by a correlation coefficient which quantifies the strength of that relationship, and which when squared, represents the proportion of variance measure R^2 described above. Unfortunately, simple scatterplots are not available as a tool when many variables are being simultaneously considered.

Comparing the effect of many factors simultaneously on personal exposure becomes very complex, not only because of the increased number of factors but also due to the numerous potential interactions between the factors. Communicating the results can also be difficult, having to describe effects due to



each factor (direct effects) and numerous interrelationships between the factors (indirect effects) that may be noteworthy. In an effort to communicate these results clearly a pictorial description of the general model used in this analysis was developed and is presented in Figure 9. The figure shows the factor groups in colored boxes interconnected with black arrows to the box representing personal exposure. A colored arrow connecting the factor and personal exposure on the right side of the figure represents the potential direct effect of each factor group on personal exposure. The potential indirect effects of each factor on personal exposure acting through the subsequent factors is shown by the cascading colored arrows on the left of the figure. The arrows are color coded to represent the factor groups. In subsequent sections of this report when this model is displayed for a contaminant only the significant effects and factor groups are displayed as is shown in Figure 11 for NO₂. The magnitude of the effect is written beside the arrow as a percentage and is reflected in the size of the arrow. The summations of the percentages on the figures will roughly total the variation described by the model that is also noted on the figure.

Figure 9: General Model of Personal Exposure Used to Investigate Direct and Indirect Effects of Factors



The measure R^2 can be tested for statistical significance. In the analyses that follow, a level of 0.01 generally attained significance and will be reported, although it should be noted that such low levels rarely have practical consequences.

The overall effectiveness of a model in describing variation in personal exposure also depends on the precision of the contaminant measures. For some contaminants with very low concentrations the majority of the unaccounted variation in personal exposure is most likely due to errors in measurement. For



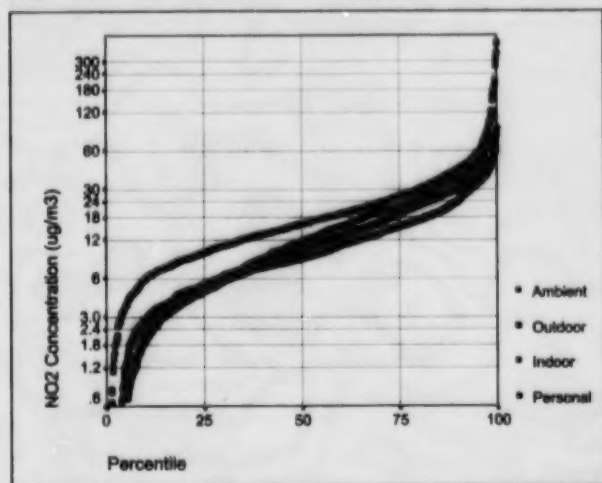
contaminants with higher concentrations, the majority of the outstanding variation is most likely due to important factors on which information was not available to be put into the model. The same degree of confidence cannot be put in the model results for the $PM_{2.5}$ and PM_{10} as the gaseous contaminants, due to the smaller sample sizes for particulate matter.

The following sections describe the major findings of the personal exposure investigation for selected contaminants both in terms of the concentrations measured and the factors affecting the variations in exposure. Further detail is presented in the *Technical Report*.

7.1 Nitrogen Dioxide Exposure

The measurements of nitrogen dioxide (NO_2) taken in Fort McMurray during the study are summarized in Figure 10 that plots each sample taken from each source in order from lowest to highest. This allows a straightforward assessment of the median and other percentile levels for the full set of samples. Levels of NO_2 were highest in personal exposures and lowest in home indoor environments. However, the overall levels were low with the majority of the samples collected falling below the method detection limit (MDL) of $18 \mu g/m^3$. While the imprecision associated with individual samples increases dramatically when measures fall below the detection limit, the data provides a prediction of overall community exposure because such a large number of samples were taken.

Figure 10: Distribution of Nitrogen Dioxide



The median and 95th percentile NO_2 levels for the different locations are summarized and compared to guidelines and levels in other communities in Table 6. In addition, the relative levels of NO_2 at the locations are compared by the ratios of personal to indoor (P/I), personal to outdoor (P/O), and indoor to outdoor (I/O). The measures taken at the ambient station with the passive samplers compare well with the collocated Wood Buffalo Environmental Association (WBEA) monitors which recorded median and 95th percentile readings of 14 and $34 \mu g/m^3$, respectively. The levels of personal exposure to NO_2 measured in Fort McMurray were comparable to those measured in Lethbridge. The indoor and outdoor levels of NO_2 were an order of magnitude below guideline levels and were similar to levels found in Lethbridge and in other relevant studies. The median indoor to outdoor ratio was higher in Fort McMurray compared to other relevant communities.



Table 6: Comparison of NO₂ Levels with Guidelines and Other Studies^{32, 33, 34}

Parameter	Units	Ft. Mc. Median	Ft. Mc. 95 th	Leth. Median	Leth. 95 th	Relevant Studies	Guideline / Reference Level
Personal	µg/m ³	15.9	53.2	17.7	41.6	N/A	N/A
Indoor	µg/m ³	8.6	30.0	9.8	30.3	6*	100 (long term) 480 (hr)***
Outdoor	µg/m ³	9.5	38.5	13.8	42.8	12*	206 (d) AEP
Ambient Station	µg/m ³	10.8	36	N/A	N/A	7 to 27**	394 (hr) 206 (d) 56 (yr) AEP
P/I ratio		1.9	1.8	1.8	1.4	N/A	N/A
P/O ratio		1.7	1.4	1.3	1.0	N/A	N/A
I/O ratio		0.90	0.78	0.71	0.71	.65*	N/A

* Hagenbjork-Gustafsson et al., 1996.

** Spengler et al., 1983.

*** Health Canada, 1989.

Numerical results of the analysis of relationships between personal exposures and the factors that may affect exposure is found in Table 7. The second column of the table shows individual factors' relationships to personal exposure if considered alone. These are the R² values that resulted from simple bivariate scatterplots of the factor and personal exposure. The third column shows the amount of variation in personal exposure described by each factor in the context of the model. The fourth and fifth columns divide this total into direct and indirect portions. Overall, the model accounted for about 40% of the variability in personal exposure levels.

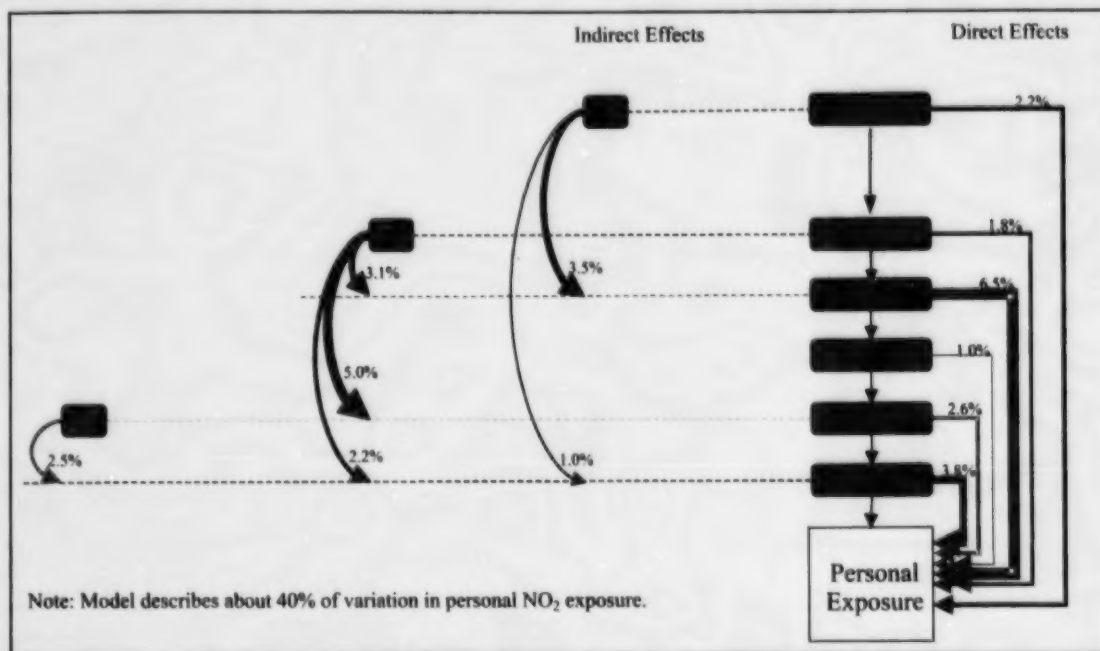
Table 7: Summary of NO₂ Personal Exposure Relationships with Model Factors

Factor	Individual Factor R ²	Combined All Factor (Model R ²)		
		Total	Direct	Indirect
Gender	0.00	0.00	0.00	0.00
Housing Characteristics	0.02	0.02	0.00	0.02
Job Status	0.09	0.08	0.02	0.06
Smoking Characteristics	0.02	0.02	0.01	0.01
Seasonal Effect	0.15	0.12	0.02	0.10
Time Activity	0.18	0.06	0.06	0.00
Specific Exposures	0.05	0.02	0.01	0.01
Outdoor Concentration	0.16	0.05	0.03	0.02
Indoor Concentration	0.13	0.04	0.04	0.00
Total Model		0.41	0.19	0.22



These model results have been represented pictorially in Figure 11. Only effects with R^2 values greater than 0.01 (i.e., 1%) are displayed.

Figure 11: Results of Model of Personal Exposure to NO_2 Showing Direct and Indirect Effects of Factors



In the general model, a large number of pathways for each indirect effect are possible. An informed guess has been made in some cases to identify the pathway for an indirect effect. Thus, the major effects on personal exposure levels identified in the analysis were:

- **Time activity**, directly (6.5%)
- **Seasonal variation**, operating indirectly through effects on outdoor levels (5.0%)
- **Indoor levels**, directly (3.8%)
- **Job status**, operating indirectly through effects on time activity patterns (3.5%)
- **Seasonal variation**, operating indirectly through effects on time activity (3.1%)
- **Outdoor levels**, directly (2.6%)
- **Outdoor levels**, operating indirectly through effects on indoor levels (2.5%)
- **Seasonal variation**, operating indirectly through effects on indoor levels (2.2%)
- **Job status**, directly (2.2%)
- **Seasonal variation**, directly (1.8%)



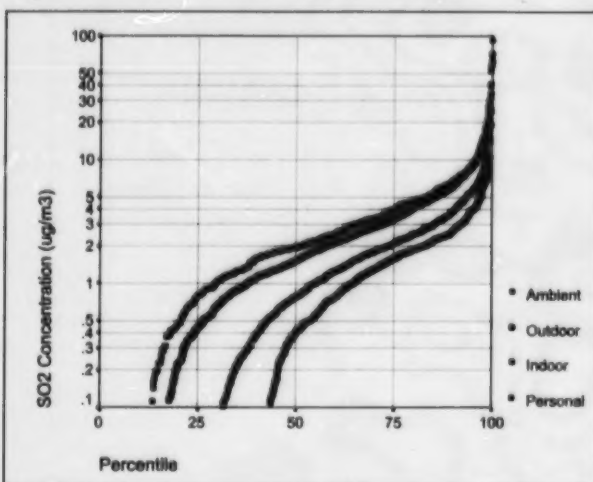
Overall, seasonal variation accounted for over one-third of the variation in personal exposure described by the model. Its largest influence was exerted through its effects on outdoor concentrations, time activity patterns, and indoor concentrations, and only directly influenced personal levels to a lesser degree. Variation in outdoor and indoor levels also accounted for roughly one quarter of the measured variation in personal exposure. Time activity was also an important driver of personal exposure.

As noted above, personal exposures were higher than those measured either indoors or outdoors. Additionally, the amount of time spent indoors at locations other than home (as some of the variables describing time activity patterns) was identified as important. Therefore, it seems likely that personal exposures were increased because individuals were exposed to higher NO_2 levels at other indoor sites. Further study is required to confirm this inference.

7.2 Sulfur Dioxide Exposure

The measurements of sulfur dioxide (SO_2) taken in Fort McMurray during the study are summarized in Figure 12. Levels of SO_2 were highest in ambient air and lowest in home indoor environments. Overall, levels were low, however, with over 80% of the samples collected falling below the MDL of $6.7 \mu\text{g}/\text{m}^3$.

Figure 12: Distribution of Sulfur Dioxide



The median and 95th percentile SO_2 levels for the different locations are summarized in Table 8 and compared to guidelines and levels in other communities. The study measures taken at the ambient station showed higher median levels of SO_2 compared to the WBEA monitors (2.0 vs. $1.1 \mu\text{g}/\text{m}^3$) while the 95th percentile measures were in agreement. The levels of SO_2 measured in Fort McMurray were much lower than guidelines but higher than those measured in Lethbridge. There were no other studies of SO_2 levels at other relevant communities to compare to these findings.



Table 8: Comparison of SO₂ Levels with Guidelines and Other Studies³⁵

Parameter	Units	Ft. Mc. Median	Ft. Mc. 95 th	Leth. Median	Leth. 95 th	Relevant Studies	Guideline / Reference Level
Personal	µg/m ³	0.87	5.6	0.21	3.1	N/A	N/A
Indoor	µg/m ³	0.41	4.1	0.16	2.9	N/A	50 (long term) 1000 (five min)*
Outdoor	µg/m ³	1.6	8.0	1.1	5.2	N/A	157 (d) AEP
Ambient Station	µg/m ³	2	6.5	N/A	N/A	N/A	445 (hr) 157 (d) 26 (yr.) AEP 39 - 60 (1 yr.) EC 340 (1 hr) WHO
P/I ratio		2.1	1.4	1.3	1.1	N/A	N/A
P/O ratio		0.53	0.70	0.19	0.59	N/A	N/A
I/O ratio		0.25	0.52	0.15	0.56	N/A	N/A

* Health Canada, 1989.

Numerical results of the analysis of relationships between personal exposures and the factors that may affect exposure is found in Table 9. The second column of the table shows individual factors relationships to personal exposure if considered alone. These are the R² values that resulted from simple bivariate scatterplots of the factor and personal exposure. The third column shows the amount of variation in personal exposure described by each factor in the context of the model. The fourth and fifth columns divide this total into direct and indirect portions. The model accounted for about 25% of the variation in personal exposure. The majority of the unexplained variation in personal exposure is likely due to sampler error.

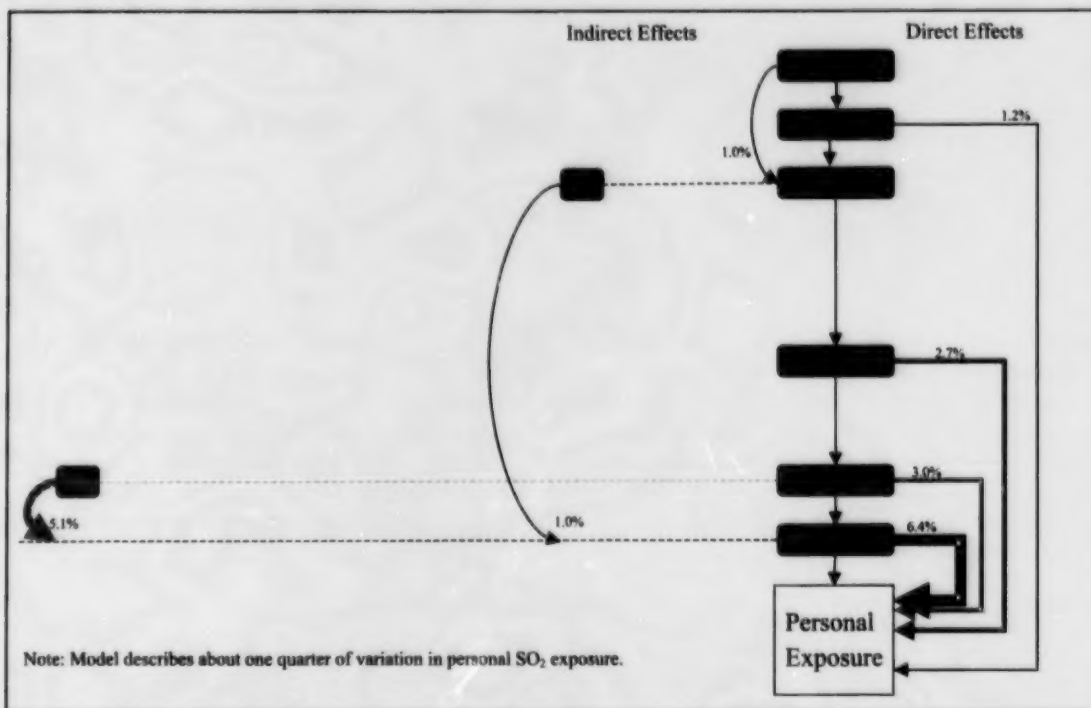
Table 9: Summary of SO₂ Personal Exposure Relationships with Model Factors

Factor	Individual Factor R ²	Combined All Factor (Model R ²)		
		Total	Direct	Indirect
Gender	0.02	0.02	0.01	0.01
Housing Characteristics	0.03	0.03	0.01	0.02
Job Status	0.03	0.02	0.00	0.02
Smoking Characteristics	0.01	0.01	0.01	0.00
Seasonal Effect	0.02	0.02	0.01	0.01
Time Activity	0.03	0.02	0.03	-0.01
Specific Exposures	0.02	0.00	0.01	0.00
Outdoor Concentration	0.08	0.08	0.03	0.05
Indoor Concentration	0.15	0.06	0.06	0.00
Total model		0.26	0.16	0.10



These model results have been represented pictorially in Figure 13. Only effects with R^2 values greater than 0.01 (i.e., 1%) are displayed.

Figure 13: Results of Model of Personal Exposure to SO_2 Showing Direct and Indirect Effects of Factors



A qualitative estimate of the pathways of the indirect effects has been made. The major effects identified in the analysis were as follows:

- **Indoor levels**, directly (6.4%)
- **Outdoor levels**, operating indirectly through effects on indoor levels (5.1%)
- **Outdoor levels**, directly (3.0%)
- **Time activity**, directly (2.7%)
- **Housing characteristics**, directly (1.2%)
- **Gender**, operating indirectly through effects on job status (1.0%)
- **Job status**, operating indirectly through effects on indoor levels (1.0%)

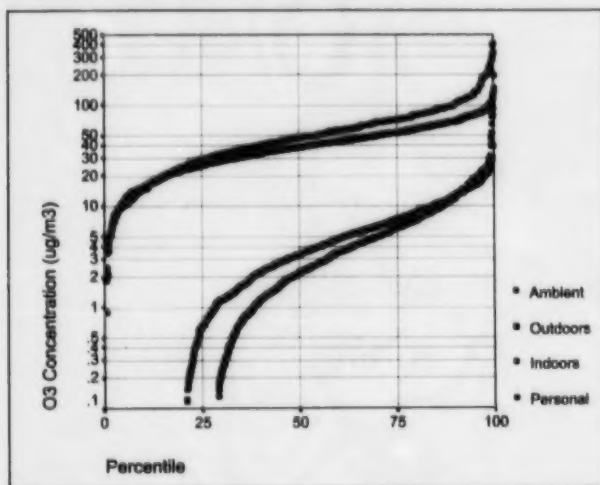
Overall, variations across houses for indoor levels (under the influence of outdoor levels) and temporal variability of outdoor levels account for roughly three-quarters of the variation in personal exposure accounted for by the model. Note that this does not mean that there were indoor sources of SO_2 , rather it suggests that differences between houses resulted in different SO_2 levels. Outdoor levels, indoor levels under the influence of outdoor levels, and time activity were also factors affecting personal exposure.



7.3 Ozone Exposure

The results of the ozone (O_3) measures taken in Fort McMurray during the study are shown in Figure 14. As the figure demonstrates, median indoor and personal levels of O_3 were less than 10% of outdoor and ambient levels. Nearly all the outdoor and ambient samples were above the MDL of $4.7 \mu\text{g}/\text{m}^3$ while the majority of the indoor and personal samples were below the MDL. The MDL achieved in this study was low compared to other studies using passive samplers.^{36, 37} While the imprecision of sample increases below the detection limit, the data can still be utilized to predict community exposure due to the large number of samples taken.

Figure 14: Distribution of Ozone



The median and 95th percentile O_3 levels for the different locations are summarized in Table 10 and compared to guidelines and levels in other communities. Levels of O_3 measured in this study were comparable to Lethbridge values. The indoor and personal levels in Fort McMurray were lower than other studies and much lower than the guideline.

The study measures taken at the ambient station showed higher median and 95th percentile levels of O_3 compared to the WBEA monitors that recorded 34.5 and $67 \mu\text{g}/\text{m}^3$, respectively. The increase in the study measures is likely due to a wind effect on the passive samplers (unaccounted for increased passive sampling rate due to increased sampler face airflow). While the wind effect was a factor for all the passive sampled contaminants in this study, there was a larger impact on the O_3 results because high ambient O_3 levels were associated with high winds magnifying the wind effect (this is unique to O_3). Accordingly, the outdoor and ambient O_3 results were inflated, particularly the 95th percentile readings. Based on the WBEA measures, the current ambient O_3 guideline for daily average concentrations ($50 \mu\text{g}/\text{m}^3$) was exceeded during the study. This guideline is often exceeded in rural areas of the province and is under review. Guidelines from other jurisdictions are considerably higher (157 U.S.EPA, 100 UK for 8 hr period).



Table 10: Comparison of O₃ Levels with Guidelines and Other Studies^{38,39, 40}

Parameter	Units	Ft. Mc. Median	Ft. Mc. 95 th	Leth. Median	Leth. 95 th	Relevant Studies	Guideline / Reference Level
Personal	µg/m ³	3.3	18	4.9	20	16 (sum.)* 2.6 (win.)*	N/A
Indoor	µg/m ³	2.4	15	2.4	11	14 (sum.)* 3.1 (win.)*	240 (hr)***
Outdoor	µg/m ³	39	91	57	140	37 (sum.)* 30 (win.)*	N/A
Ambient Station	µg/m ³	50	100	N/A	N/A	N/A	50 (d) AEP
P/I ratio		1.3	1.2	2.0	1.8	1.2 (sum.)* .81 (win.)*	N/A
P/O ratio		0.08	0.20	0.09	0.15	.43 (sum.)* .08 (win.)*	N/A
I/O ratio		0.06	0.16	0.04	0.08	.41** .37 (sum.)* .10 (win.)*	N/A

* Lui, et al., 1995.

** Bernard et al., 1999.

*** Health Canada, 1989.

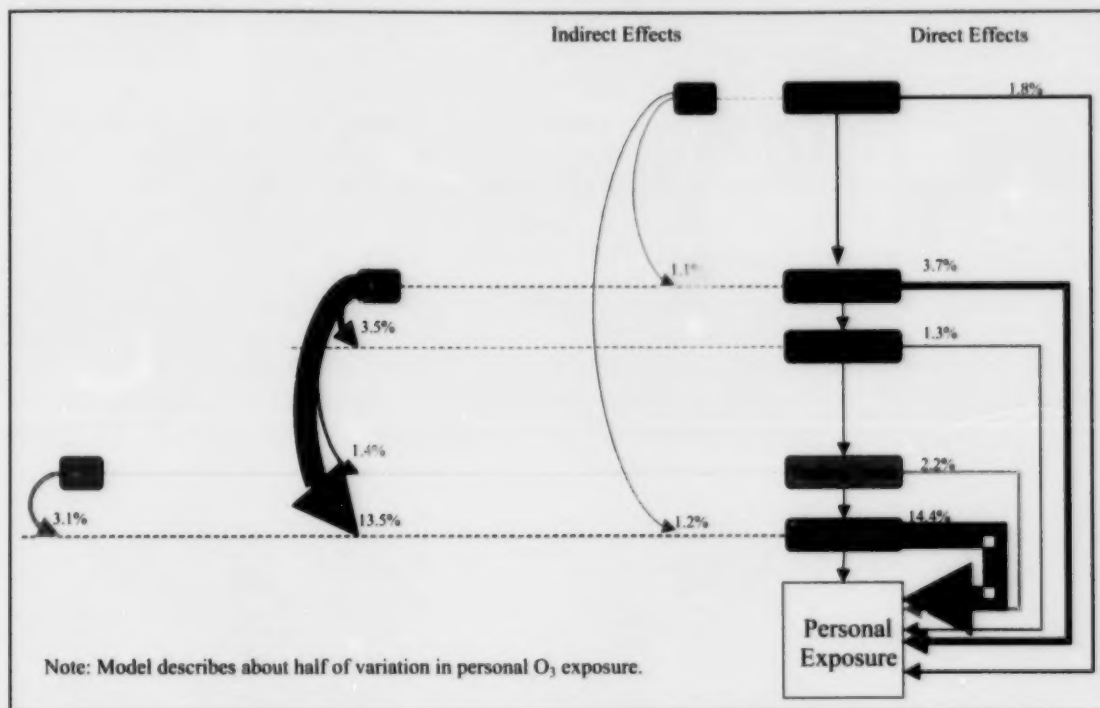
The results of the analysis comparing effects of factors on personal O₃ exposure is shown in Table 11 and pictorially in Figure 15.

Table 11: Summary of O₃ Personal Exposure Relationships with Model Factors

Factor	Individual Factor R ²	Combined All Factor (Model R ²)		
		Total	Direct	Indirect
Gender	0.01	0.01	0.00	0.01
Housing Characteristics	0.06	0.06	0.02	0.04
Job Status	0.01	0.01	0.00	0.00
Smoking Characteristics	0.00	0.00	0.01	0.00
Seasonal Effect	0.23	0.22	0.04	0.18
Time Activity	0.09	0.02	0.01	0.01
Specific Exposures	0.01	0.01	0.01	0.00
Outdoor Concentration	0.12	0.05	0.02	0.03
Indoor Concentration	0.37	0.14	0.14	0.00
Total model		0.52	0.25	0.27



Figure 15: Results of Model of Personal Exposure to O₃ Showing Direct and Indirect Effects of Factors



The model predicted about half of the variation in personal O₃ exposure across individuals and days. Important factors influencing variations in O₃ exposures were as follows:

- **Indoor levels**, directly (14.4%)
- **Seasonal variation**, operating indirectly through effects on indoor levels (13.5%)
- **Seasonal variation**, directly (3.7%)
- **Seasonal variation**, operating indirectly through effects on time activity (3.5%)
- **Outdoor levels**, operating indirectly through effects on indoor levels (3.1%)
- **Outdoor levels**, directly (2.2%)
- **Housing characteristics**, directly (1.8%)
- **Seasonal variation**, operating indirectly through effects on outdoor air (1.4%)
- **Time activity**, directly (1.3%)
- **Housing characteristics**, operating indirectly through effects on indoor air (1.2%)
- **Housing characteristics**, operating indirectly through effects on seasonal effects (1.1%)



The majority of variations in personal exposure described by the model were due to indoor concentrations that were heavily influenced by seasonal effects (lower concentrations in winter) and influenced to a lesser degree by outdoor concentrations. Overall, indoor and outdoor levels explained over 30% and under 5% of the variance in personal O_3 levels respectively. Seasonal variation was an important effect that appears to impact personal exposure independently of outdoor concentrations (i.e., by affecting time activity, specific exposures and indoor concentration).

It cannot be over emphasized that outdoor concentrations were not found to be a good surrogate measure of personal exposures in this study. Personal levels were only 10% of outdoor levels and changes in outdoor concentrations accounted for less than 5% of the variation in personal exposures.

7.4 Benzene and VOCs Exposure

The results of the benzene measurements taken in Fort McMurray during the study are shown in Figure 16. The majority of the samples were below the MDL of $4.3 \mu\text{g}/\text{m}^3$ but a good prediction of community exposure is still provided by the large number of samples taken. As the figure shows, the highest levels of benzene were found in the personal exposure samplers, while the lowest levels were measured in outdoor and ambient air. This pattern was generally duplicated in other VOC exposures as detailed in the *Technical Report*.

Figure 16: Distribution of Benzene

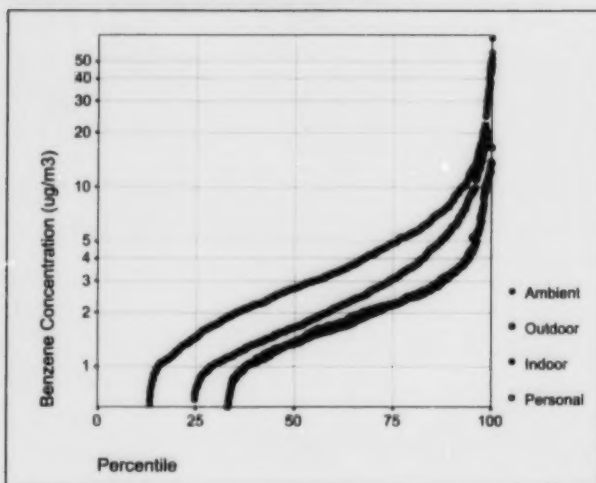


Table 12 contains a summary of the benzene measures taken during the study showing the median and 95th percentile levels compared to guidelines and levels at other relevant communities. With fewer samples taken in Lethbridge during the study, estimates of median indoor and outdoor levels were not reliable and are not included. The outdoor and ambient benzene levels were low and comparable to levels reported for rural areas in Canada. The median personal levels were roughly 2.5 times the ambient levels and roughly 20% of the levels reported in the TEAM study. The TEAM study also found that the highest levels of benzene were from the personal samplers, followed by the indoor sampler levels, while the outdoor samplers contained the lowest levels of benzene.⁴¹



Table 12: Comparison of Benzene Levels with Guidelines and Other Studies^{42, 43}

Parameter	Units	Ft. Mc. Median	Ft. Mc. 95 th	Leth. Median	Leth. 95 th	Relevant Studies	Guideline / Reference Level
Personal	µg/m ³	2.8	10.0	2.1	6.7	15 (TEAM)**	N/A
Indoor	µg/m ³	1.7	6.6	*	4.8	10 (TEAM)**	N/A
Outdoor	µg/m ³	1.3	5.5	*	3.6	2.6***	N/A
Ambient Station	µg/m ³	1.2	3.1	N/A	N/A	4.4 (Canadian urban) 0.6 to 1.2 (rural)**	16 UK current 3.2 UK future
P/I ratio		1.7	1.5	N/A	1.4	1.5**	N/A
P/O ratio		2.05	1.82	N/A	1.90	2.5**	N/A
I/O ratio		1.23	1.20	N/A	1.34	1.7**	N/A

* Estimate not available due to small number of Lethbridge samples.

** Wallace, 1996.

*** Median value from monitoring across Canada (Dann et al., 1995).

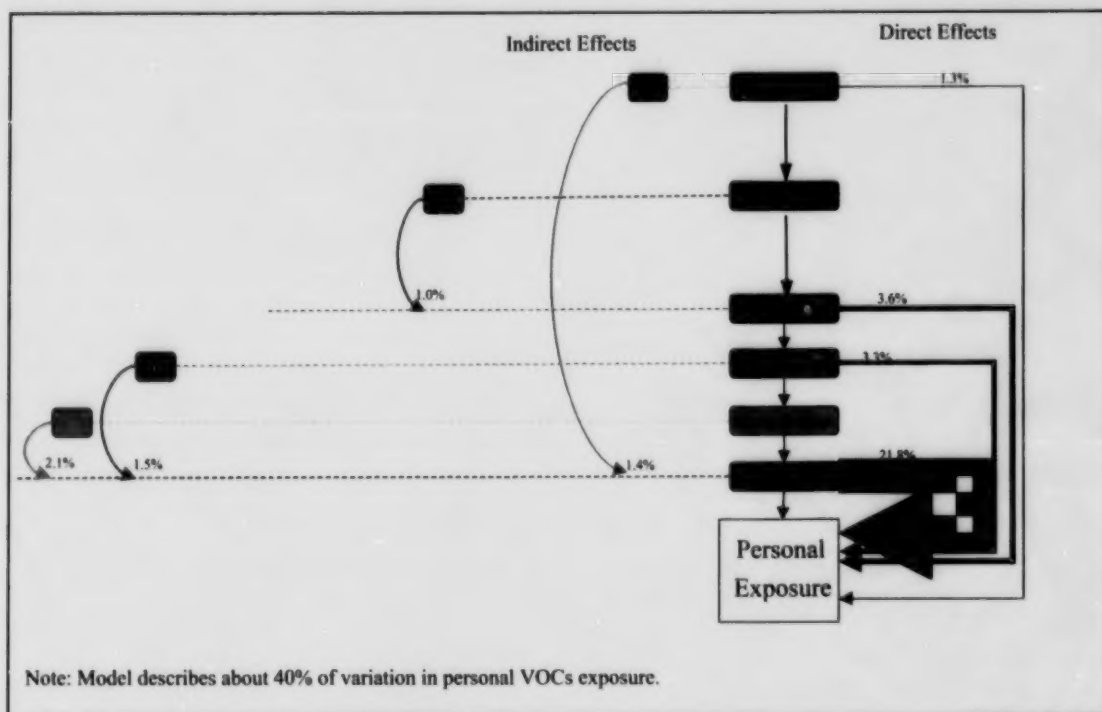
The benzene measures were combined with the measures of other VOCs for the investigation into the factors that were important to exposures. The results of the analysis are presented in Table 13 and pictorially in Figure 17.

Table 13: Summary of VOC Personal Exposure Relationships with Model Factors

Factor	Individual Factor R ²	Combined All Factor (Model R ²)		
		Total	Direct	Indirect
Gender	0.02	0.02	0.01	0.01
Housing Characteristics	0.03	0.04	0.01	0.02
Job Status	0.02	0.01	0.00	0.00
Smoking Characteristics	0.02	0.02	0.01	0.01
Seasonal Effect	0.01	0.01	0.01	0.00
Time Activity	0.07	0.05	0.04	0.01
Specific Exposures	0.07	0.05	0.03	0.02
Outdoor Concentration	0.03	0.02	0.00	0.02
Indoor Concentration	0.28	0.22	0.22	
Total model		0.43	0.33	0.10



Figure 17: Results of Model of Personal Exposure to VOCs Showing Direct and Indirect Effects of Factors



The final model predicted about 40% of the variation in personal VOCs exposure across individuals and days. Indoor concentrations were the predominant factor affecting personal exposure; the other factors were of only minor relative importance. This suggests that exposure to these chemicals were predominantly from sources affecting indoor levels. Outdoor concentrations did not have a significant direct effect on personal exposure but had a small indirect effect through indoor air, accounting for about 2% of the variation in personal exposure.

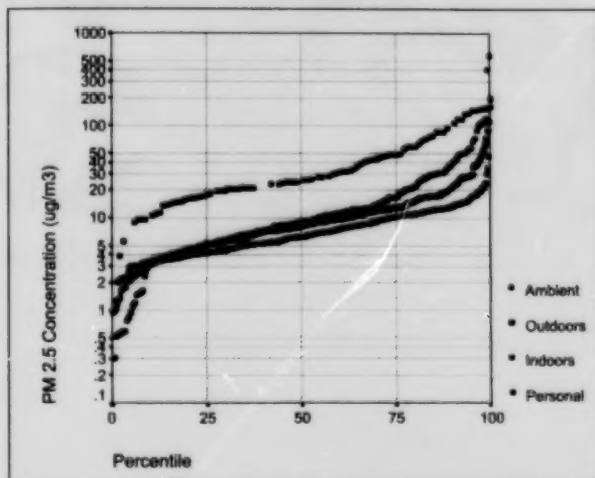
Additional investigations during the study located high VOCs concentrations in some house garages and in service stations. This agrees with other studies that found that attached garages had a significant impact on indoor and personal benzene levels.⁴⁴

7.5 Particulate Matter 2.5 μ m Exposure

Measures of particulate exposure were obtained from a sub-sample of participants from Fort McMurray and Lethbridge. The results of the PM_{2.5} measures taken in Fort McMurray are shown in Figure 18. Nearly all the samples taken were above the MDL of 2.5 μ g/m³. Personal exposures were the highest while the ambient station had the lowest levels. Indoor and outdoor measures were similar at the median values while indoor levels were higher above the 75th percentile.



Figure 18: Distribution of PM_{2.5}



The median and 95th percentile PM_{2.5} levels for the different locations are summarized in Table 14 and compared to guidelines and levels in other communities. The PM_{2.5} measures taken at the ambient station compared well with the WBEA real time PM_{2.5} monitors that recorded daily median and 95th percentile readings of 6.6 and 19.8 µg/m³, respectively. The levels of personal and indoor exposure to PM_{2.5} measured in Fort McMurray were higher than those measured in Lethbridge likely due to the fact that there were fewer smokers among the Lethbridge particulate sub-sample. When comparing only non-smokers, the levels were similar. The indoor median concentrations were below recommended guidelines but the 95th percentile value exceeded the guidelines. The P/I ratio was similar to Lethbridge but higher than other reported values. The outdoor levels of PM_{2.5} were slightly higher than in Lethbridge but below the guideline values.

Table 14: Comparison of PM_{2.5} Levels with Guidelines and Other Studies^{45, 46, 47}

Parameter	Units	Ft. Mc. Median	Ft. Mc. 95 th	Leth. Median	Leth. 95 th	Relevant Studies	Guideline / Reference Level
Personal	µg/m ³	25	88	22.3	27.4	18.7*	N/A
Indoor	µg/m ³	8.6	35	6.7	12.3	15.4*	40 long term*** 100 (hr)***
Outdoor	µg/m ³	8.4	23.2	6.3	16.8	13.2*	N/A
Ambient Station	µg/m ³	6.2	13.3	N/A	N/A	9**	15 (yr.) 65 (d) USEPA
P/I ratio		2.7	2.6	3.3	2.2	1.21*	N/A
P/O ratio		3.20	4.88	3.55	1.64	1.42*	N/A
I/O ratio		1.17	1.88	1.06	0.73	1.17*	N/A

* Pellizzari et al., 1999.

** Cheng et al., 1998.

*** Health Canada, 1989.

The results of the analysis of relationships between personal exposures and the factors that may affect exposure are found in Table 15 and pictorially in Figure 19. The model examined the relationship

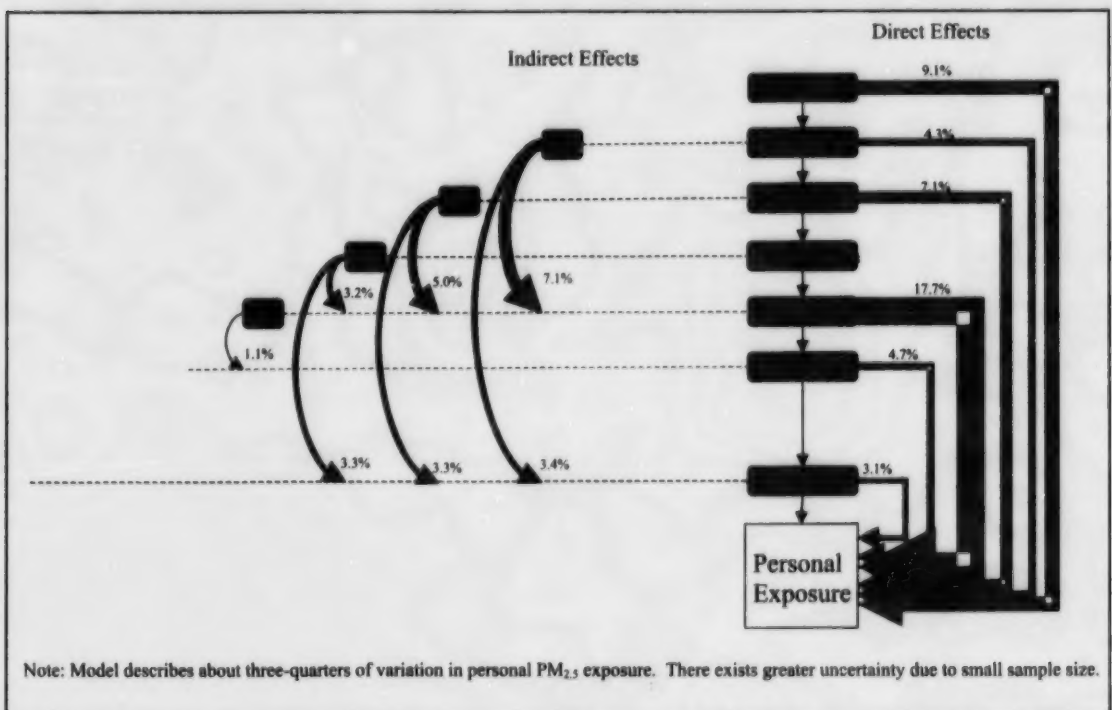


between the combined variability of all factors and the variation in personal exposure. The model accounted for about three-quarters of the variation in personal exposure. However, because the sample size is very small for this analysis, there is greater uncertainty associated with these estimates. The unexplained variation in personal exposure is likely due to sampler error and other factors that were not included in the model.

Table 15: Summary of PM_{2.5} Personal Exposure Relationships with Model Factors

Factor	Individual Factor R ²	Combined All Factor (Model R ²)		
		Total	Direct	Indirect
Gender	0.00	0.00	0.00	0.00
Housing Characteristics	0.09	0.09	0.13	-0.03
Job Status	0.08	0.16	0.04	-0.11
Smoking Characteristics	0.24	0.16	0.07	0.08
Seasonal Effect	0.09	0.08	0.00	0.08
Time Activity	0.29	0.19	0.18	0.01
Specific Exposures	0.11	0.04	0.05	-0.01
Outdoor Concentration	0.00	0.00	0.01	0.00
Indoor Concentration	0.12	0.03	0.03	0.00
Total model		0.75	0.51	0.24

Figure 19: Results of Model of Personal Exposure to PM_{2.5} Showing Direct and Indirect Effects of Factors





Important factors influencing variations in $PM_{2.5}$ exposures were as follows:

- *Time activity*, directly (17.7%)
- *Housing characteristics*, directly (9.1%)
- *Job status*, operating indirectly through effects on time activity (7.1%)
- *Smoking characteristics*, directly (7.1%)
- *Smoking characteristics*, operating indirectly through effects on time activity (5.0%)
- *Specific exposures*, directly (4.7%)
- *Job Status*, directly (4.3%)
- *Job Status*, operating indirectly through effects on indoor air (3.4%)
- *Smoking characteristics*, operating indirectly through effects on indoor air (3.3%)
- *Seasonal Effect*, operating indirectly through effects on indoor air (3.3%)
- *Seasonal Effect*, operating indirectly through effects on indoor air (3.2%)
- *Indoor levels*, directly (3.1%)
- *Time activity*, operating indirectly through effects on specific exposures (1.1%)

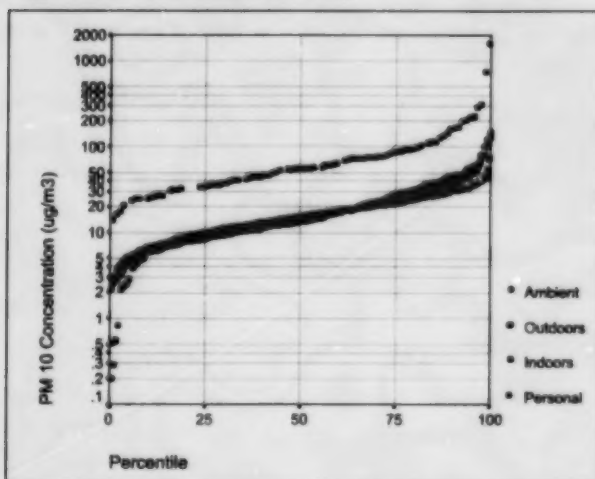
Variability in time activity, smoking, and job status were the dominant factors explaining variation in personal exposure to $PM_{2.5}$ accounting for over two thirds of the variation explained by the model. Time activity had an important impact on personal exposures both directly (17%) and as a pathway through which for other factors act (about 15%). Variation in the time spent outdoors at work was the most important component of the time activity effect. In addition to smoking being an important factor alone (15.4%), variables related to smoke were mainly responsible for the effect of specific exposures (4.7%). Outdoor concentrations were not important as either a driver or a pathway of personal exposure to $PM_{2.5}$.

7.6 Particulate Matter $10\mu m$ Exposure

The results of the PM_{10} measures taken in Fort McMurray are shown in Figure 20. Nearly all the samples taken were above the MDL of $2.5 \mu g/m^3$. Personal exposures were highest while the ambient station had the lowest levels. Indoor levels were slightly higher than outdoor levels.



Figure 20: Distribution of PM₁₀



The median and 95th percentile PM₁₀ levels for the different locations are summarized in Table 16 and compared to guidelines and levels in other communities. The median levels of personal exposure to PM₁₀ measured in Fort McMurray were higher than those measured in Lethbridge while outdoor levels were lower and personal levels were the same. Outdoor and ambient levels were below recommended guidelines. Indoor and outdoor levels were lower in Fort McMurray than those reported elsewhere while personal exposure was slightly higher. The P/I, P/O, and I/O ratios were all higher in Fort McMurray, which indicates more personal and indoor sources of exposure for those participants.

Table 16: Comparison of PM₁₀ Levels with Guidelines and Other Studies^{48, 49}

Parameter	Units	Ft. Mc. Median	Ft. Mc. 95 th	Leth. Median	Leth. 95 th	Relevant Studies	Guideline / Reference Level
Personal	µg/m ³	57.3	168.0	33.9	65.1	48.5*	N/A
Indoor	µg/m ³	15.1	46.7	15.4	24.1	23.1*	N/A
Outdoor	µg/m ³	12.4	35.6	16.3	42.5	23.6*	N/A
Ambient Station	µg/m ³	15.2	30.6	N/A	N/A	23 – 27**	50 (yr.) 150 (d) USEPA
P/I ratio		3.8	3.6	2.2	2.7	2.10*	N/A
P/O ratio		4.62	4.72	2.08	1.53	2.06*	N/A
I/O ratio		1.21	1.31	0.95	0.57	0.98*	N/A

* Pellizzari et al., 1999.

** Cheng et al., 1998.

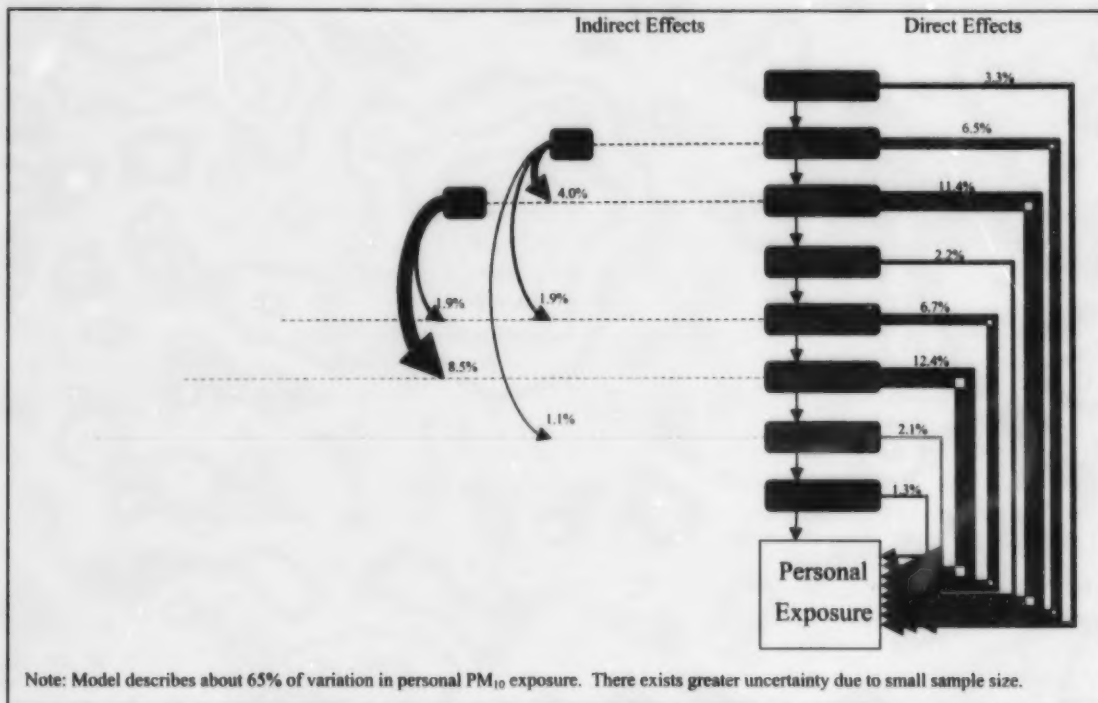
The results of the analysis of relationships between personal exposures and the factors that may affect exposure is found in Table 17 and shown pictorially in Figure 21. The model (see Figure 21) examined the relationships between all factors combined and personal exposure and accounted for about 65% of the variation in personal exposure. However, because the sample size is very small for this analysis, there is greater uncertainty associated with these estimates. The unexplained variation in personal exposure is likely due to important factors that were not included in the model.



Table 17: Summary of PM₁₀ Personal Exposure Relationships with Model Factors

Factor	Individual Factor R ²	Combined All Factor (Model R ²)		
		Total	Direct	Indirect
Gender	0.01	0.01	0.00	0.01
Housing Characteristics	0.02	0.02	0.03	-0.02
Job Status	0.12	0.14	0.06	0.08
Smoking Characteristics	0.18	0.22	0.11	0.11
Seasonal Effect	0.05	0.04	0.02	0.01
Time Activity	0.08	0.07	0.07	0.00
Specific Exposures	0.11	0.11	0.12	-0.01
Outdoor Concentration	0.03	0.02	0.02	0.00
Indoor Concentration	0.05	0.01	0.01	0.00
Total Model		0.65	0.46	0.19

Figure 21: Results of Model of Personal Exposure to PM₁₀ Showing Direct and Indirect Effects of Factors





Important factors influencing variations in PM_{10} exposures were as follows:

- *Specific exposures*, directly (12.4%)
- *Smoking characteristics*, directly (11.4%)
- *Smoking characteristics*, operating indirectly through effects on specific exposures (8.5%)
- *Time activity*, directly (6.7%)
- *Job status*, directly (6.5%)
- *Job status*, operating indirectly through effects on smoking characteristics (4.0%)
- *Housing characteristics*, directly (3.3%)
- *Seasonal effects*, directly (2.2%)
- *Outdoor levels*, directly (2.1%)
- *Smoking characteristics*, operating indirectly through effects on time activity (1.9%)
- *Job status*, operating indirectly through effects on time activity (1.8%)
- *Indoor levels*, directly (1.3%)

The model demonstrates that smoking characteristics, job status and specific exposures were important factors affecting PM_{10} personal exposures and accounted for roughly three-quarters of the variation explained by the model. Indoor and outdoor levels were responsible for less than 5% of the variance in personal PM_{10} . Important factors influencing variation in personal exposure did not exert effects through indoor and outdoor concentration levels. Finally, ambient concentrations were not a good predictor of personal exposures.

7.7 *Electron Microscopy*

Particulate air filter samples were analyzed from the Fort McMurray region for the presence and type of organic, mineral, and metal particles. Samples were obtained from three locations: outdoor, indoor, and personal, and within two size ranges ($<10\ \mu m$ and $<2.5\ \mu m$). Samples were prepared for scanning electron microscopy and x-ray microanalysis by coating with either carbon or gold/vanadium and examined in both back-scattered and secondary electron modes. Semi-quantitative classification of mineral and metal particles was based upon net fractional x-ray intensities.

The types of organic-based particles differed according to the filter location. For outdoor filters, pollen spores predominated. For indoor filter samples, moulds, squames (dander material), hairs, and fabric fibers were predominant. For all filter types, aluminum silicates, silica, and calcium containing minerals predominated. There were no specific differences between indoor, outdoor, and personal samplers for mineral or metal classes. The types of mineral particles and their relative frequencies were similar to those described for atmospheric samples taken in rural Alberta.⁵⁰ For further detail regarding the electron microscopy component refer to the *Technical Report* and the *Methods Report*.



8.0 Biomarkers of Exposure

Urine and blood samples were collected at the end of the period of study for each participant. The samples were sent to various laboratories that performed a series of tests to determine the levels of various contaminants.

The analysis of the blood samples included measures of nicotine and arsenic speciation, while the analysis of the urine samples included measures of BTEX compounds. The results from the heavy metal analysis in urine and blood were not available at the time of publication.

8.1 Nicotine

Blood samples from 214 Fort McMurray participants and 30 Lethbridge participants were analyzed for nicotine content. The level of nicotine was clearly related to smoking behavior. A regression analysis of nicotine levels against reported smoking habit variables showed that the following variables were independently related to nicotine levels: amount smoked, allowing smoking in the car, and number of test days exposed to smoke. Allowing smoking in the home was not independently related to blood nicotine levels.

8.2 Arsenic Speciation

High Performance Liquid Chromatography (HPLC) with Hydride Generation Atomic Fluorescence Detection (HGAFD) method was used for the speciation of arsenic compounds. Detailed methodology has been previously described by Le and Ma.⁵¹ Additional information regarding the methodology of the analysis can be found in the *Methods Report*.

Speciation of arsenic in urine and blood was carried out using the same methodology in 101 Fort McMurray and 30 Lethbridge participants. Urinalysis revealed that concentrations of arsenic were very low, comparable to individuals who had no known exposure to arsenic in a previous study.⁵² Arsenic levels in the urine of Fort McMurray and Lethbridge participants reflected normal background concentrations. Only four blood serum samples (3 from Fort McMurray and 1 from Lethbridge) had detectable, although still very low, levels of arsenic. The remainder of the serum samples had arsenic concentrations below the detection limit.

8.3 BTEX Compounds

As shown previously in Table 1, the BTEX compounds include benzene, toluene, ethylbenzene, and xylene. The products of the metabolism of these compounds can be measured in the urine. A total of 242 samples of urine, 213 from Fort McMurray and 29 from Lethbridge, were analyzed for the metabolites displayed in Table 18.

Table 18: BTEX Compounds and Metabolites

Metabolite ($\mu\text{g/mL}$ in urine)	Is evidence of exposure to ...
Muconic acid	Benzene
Hippuric acid	Toluene
Mandelic acid	Ethylbenzene
3, 4-Methylhippuric acid	m-, p-xylene
2-Methylhippuric acid	o-xylene



Very few individuals showed appreciable levels of mandelic acid, 3,4-methylhippuric acid, or 2-methylhippuric acid. Further analysis did not reveal any relationship between personal exposure to ethylbenzene or xylene and these biomarker levels. Measurable amounts of muconic acid and hippuric acid were discovered, however. Relationships between exposure and biomarkers of exposure were examined by combining the personal exposure measurements for each of the four days together for each of benzene and toluene. Principal Component analysis showed mild relationships in the expected directions, that is, greater measured exposure to benzene and toluene was associated with higher levels of muconic acid and hippuric acid in the urine. However, because exposure levels were all so low, the relationship was not strong enough to be statistically significant.

9.0 Biomarkers of Effect

The biomarkers of effect included in the Alberta Oil Sands Community Exposure and Health Effects Assessment Program consisted of a measure of immune system reaction (autoantibody titers), a neurocognitive assessment, and a respiratory health assessment, including a respiratory health survey and spirometry measures.

9.1 Autoantibodies

A comparison of the prevalence of antinuclear autoantibodies (ANA) in the two populations with a healthy population can indicate whether there is evidence of immune system reaction in the sample population. A total of 244 samples were analyzed for ANA, 214 from Fort McMurray and 30 from Lethbridge. The percentage of samples that were positive for autoantibodies was 16.4% ($n = 244$) for the total group, 16.4% ($n = 214$) for the Fort McMurray participants, and 16.7% ($n = 30$) of the Lethbridge participants. This difference is not large enough to be statistically significant, and the values are comparable to the findings of Tan et al., who found that 13% of healthy individuals have antinuclear antibodies.⁵³

The Lethbridge and Fort McMurray participants did, however, differ in titer positives and autoantibody patterns: of the 35 Fort McMurray participants who tested positive for ANA, 18 had titers of at least 1:320, while none of the Lethbridge positives had a titer greater than 1:160. As well, the Fort McMurray group had more samples with antibodies to the nucleolus and patterns suggesting antibodies to DNA or histones. Higher ANA titers have been associated with disease states, but the difference may simply be a result of the small number of samples from Lethbridge.

9.2 Lung Function

Spirometry measures were collected for the five consecutive days that the participants were set up with the exposure monitors. The field monitoring team conducted spirometry testing each evening when they visited the participants. When spirometry is performed, the results are compared with a set of normal or predicted values based upon a participant's age, height, and gender.⁵⁴ Reference values are calculated using prediction equations derived from previous epidemiologic studies involving healthy, non-smoking adult populations without a history of disease that could compromise their ventilatory function. Reference values come from studies that are conducted using both equipment and methods compatible with present standards.⁵⁵ Two diagnostically important spirometric test measurements are forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1). Specifically, FVC refers to the maximal amount of air that can be forcefully exhaled after a full inhalation. FEV_1 is the volume of air exhaled during the first second of the FVC maneuver. The normal range for both FVC and FEV_1 is 80-120% of predicted values.



There were no statistically significant differences between the Lethbridge and Fort McMurray samples; FVC was actually higher than the predicted values (111.1%) and FEV₁ was 100.5% of the values predicted by the reference equations of Crapo et al., 1982,⁵⁶ reflecting normal lung function.

9.3 Immunoglobulin gamma E

The study included several measures to account for health effects such as allergies unassociated with exposure to airborne chemicals. One of the best markers of genetically inherited allergies is the excessive production of Immunoglobulin gamma E (IgE). High levels of IgE are associated with an increased incidence of diseases including bronchial asthma, allergic rhinitis, and eczema. A comparison of the total serum IgE level in the two sample populations with reference populations from previous studies can indicate whether there is evidence of increased allergic response in the sample population.

A total of 242 samples were analyzed for total IgE serum levels, 214 from Fort McMurray and 28 from Lethbridge. The mean serum IgE of 98.03 kU/L for the Fort McMurray group was not significantly different from the mean serum IgE from the Lethbridge group of 100.31 kU/L. There was also no significant difference found when these IgE levels were compared to a previous study's control group.⁵⁷

The Phadiatop test, a screening test for IgE to specific common inhalant allergens, was also completed. A positive result means that one or more antibodies were present to the following allergens: Timothy grass, dandelion, silver birch, cat dander, dog epithelium, horse dander, rye, alternaria tenuis, house dust and dermatophagoides pteronyssinus. A significant finding was the high proportion of subjects in Fort McMurray (43%) and Lethbridge (53.6%) with a positive screen for one or more inhalant allergens, which would indicate a high level of atopy in these two Alberta populations.

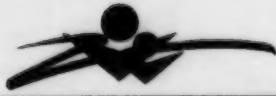
9.4 Neurocognitive Functioning

Neuropsychological assessment was conducted to provide a non-invasive means of evaluating associations between exposure and effects on neurocognitive function. Participants completed the Neurobehavioral Evaluation System (NES2), Neuropsychological Impairment Scale (NIS), and the Verbal Digit Span section of the Wechsler Memory Scale - Revised (WMS - R).

9.4.1 Neurobehavioral Evaluation System (NES2)

The NES2 is a computerized program that assesses a number of basic neurological and cognitive parameters, including finger tapping, continuous performance, hand-eye coordination, associate learning, simple reaction time, symbol-digit, pattern comparison, pattern memory, serial digit learning, switching attention, colour-word, and delayed associate recognition. Overall, there were no significant differences between the Fort McMurray and Lethbridge samples, or between either of the samples and unexposed controls from other studies, except that the Fort McMurray group performed significantly better on the dominant-hand subtest of the finger tapping test. The *Technical Report* contains the actual scores and references to the studies cited for comparisons.

The NES2 program also included a questionnaire to collect information about symptoms that are often associated with exposure to neurotoxic agents. This subjective questionnaire requires participants to indicate how often they experienced each of a number of symptoms in the past month from 1 = "not at all" to 4 = "a lot". The majority of the participants indicated they had not experienced most of the symptoms listed. A small percentage of Fort McMurray participants indicated frequently experienced symptoms: feeling tired (14.9%), having to make notes to remember things (10.2%), lack of sexual drive (6.8%), having difficulty falling asleep (6.1%), and dry skin (5.4%). Lethbridge participants indicated



that they frequently experienced: lack of sexual drive (15.2%), feeling tired (15.2%), dry skin (9.1%), having to make notes to remember (9.1%), and indigestion (6.1%).

The items of the symptoms questionnaire can be further combined to form seven scales. These composite scales measure lassitude (weariness), neurasthenia (experience of physical symptoms such as tiredness or exhaustion with no physical justification), memory, confusion, co-ordination, neurological symptoms, and physical symptoms. Overall, the symptoms questionnaire provides no indication that either population falls outside of a healthy range.

9.4.2 Neuropsychological Impairment Scale (NIS)

The Neuropsychological Impairment Scale (NIS) was developed as a self-reported questionnaire consisting of 50 items. These 50 items measure potential neuropsychological symptoms concerned with language usage, memory, sensory capacities, head injuries, motor capacities, frustration tolerance, and mental alertness. The NIS can be used to identify general neurocognitive deficits and as a useful research tool for evaluating neurocognitive impairments in the general population.

The NIS scores of Fort McMurray and Lethbridge participants were compared to norms used in previous studies.^{58,59,60} No significant differences were found between the Lethbridge and Fort McMurray samples or between participants of this study and the control groups of the above-mentioned studies.

9.4.3 Verbal Digit Span

The Verbal Digit Span from the Wechsler Memory Scale – Revised (WMS – R) was administered to each participant to include an assessment of auditory processing. The verbal digit span test consists of repeating increasingly long strings of numbers either forwards or backwards, and is a good measure of short-term memory. The mean scores for this test did not differ significantly between the Fort McMurray and Lethbridge samples. As well, the means for the two sample populations were very comparable to the results of other researchers. The *Technical Report* contains additional detail regarding the neurocognitive assessments.

10.0 Measures of Health

Several standardized questionnaires were included to obtain measures of the participant's perceived health, as well as measures of mental and psychosocial health. The data collected using the three questionnaires are discussed below.

10.1 Occupational Health Questionnaire

A standard occupational health questionnaire was used to measure symptoms typically associated with the work environment.⁶¹ The questionnaire uses a standard list of symptoms typically associated with indoor air quality, and requires the respondent to specify the location where the symptom is felt. Respondents were allowed to specify as many locations as necessary. There was no significant difference in reporting of symptoms or location between Fort McMurray participants and Lethbridge participants. The symptoms reported most frequently overall include headaches, cold and flu, dry skin, physical fatigue, back pain, eye irritation, and mental fatigue. Participants reported experiencing cold and flu, dry skin, headaches, and physical fatigue as occurring most frequently at home, and strained eyes, mental fatigue, eye irritation, and difficulty concentrating as occurring most frequently at work.



10.2 General Health Questionnaire (GHQ)

The General Health Questionnaire (GHQ) is a self-administered screening questionnaire designed to detect current, diagnosable psychiatric disorders.⁶² In each location, approximately 80% of the respondents' scores were classified as healthy and there were no statistically significant differences.

10.3 Medical Outcomes Study Short Form (SF-36)

The Medical Outcomes Study developed the 36-item Short Form (SF-36) as a standard questionnaire intended to provide a general indicator of health status for use in population health surveys.⁶³ Scores from the Fort McMurray and Lethbridge participants were compared with the scores of a reference population.⁶⁴ Differences in the overall score between the two sample populations and the reference population were not statistically significant. While there were some differences between the Lethbridge and Fort McMurray samples on a few sub-scales of the SF-36, they are likely attributable to the small size of the control group.

10.4 Previous Diagnoses

Study participants were asked to indicate which of a series of chronic diseases they have had diagnosed by a physician. The proportion of the sample population diagnosed with each chronic condition in Fort McMurray is very similar to the proportion of the Lethbridge population diagnosed with those conditions. Differences between the two populations are likely due to the small sample size in the control community. Allergies (46%) and back problems (22.3%) were diagnosed most frequently for Fort McMurray residents, and allergies (43.3%), arthritis (26.7%), and asthma (26.7%) were diagnosed most frequently for Lethbridge residents. Three percent (3%) of the Lethbridge sample indicated they had been diagnosed with cancer, and approximately the same proportion of the Fort McMurray sample indicated they had been diagnosed with some form of cancer. Compared to the Lethbridge sample (13%), a larger proportion of the Fort McMurray sample (21.5%) indicated that they had not been diagnosed with any of the chronic conditions on the list.

11.0 Analysis of Health Records

This section of the analysis was designed to address two major concerns: (1) the degree to which the study samples were representative of their populations in terms of overall health or illness, and (2) to compare rates of illness and death from selected diseases between Fort McMurray residents and their referents in Lethbridge. For this purpose, a database was constructed by linking the Alberta Health Care Insurance Plan (AHCIP) Stakeholder Registry, the Alberta Physician Claims File, the Alberta Hospital Morbidity File, and the Alberta Vital Statistics Mortality File. This database provided demographic, socioeconomic, and residential history information, linked by individual and/or geographic area to information about physician visits, hospital stays, and deaths. A population cohort from the two cities was created from the AHCIP database and records for the members of the cohort were followed from April 1, 1995 or thereafter, until either March 31, 1998, or until the individual died or moved out of the area. Overall, there were 42,356 people residing in Fort McMurray and 90,289 people residing in Lethbridge between April, 1995 and March, 1998. Of these, 29,368 from Fort McMurray and 70,390 from Lethbridge were followed-up for three years. The analysis included estimated incidence, prevalence, and mortality rates of selected diseases for each area. Multivariate logistic regression was used to control for the impact of potential confounding from age, sex, treaty status, socioeconomic status, and population mobility. The majority of the assessment used a prospective cohort design approach, and



the assessment from this approach was limited to permanent residents (21,612 from Fort McMurray and 55,079 from Lethbridge).

The following section presents the major findings of an examination of morbidity and mortality in the two communities. The complete analysis is detailed in the *Technical Report* and the *Methods Report*.

Figure 22 shows that there were no significant differences found, across communities by gender, in the proportions of physician visits, hospitalizations, and both (i.e., physician visit and hospitalization) for asthma.

Figure 22: Percentages of All Physician Visits and Hospitalization Attributed to Asthma

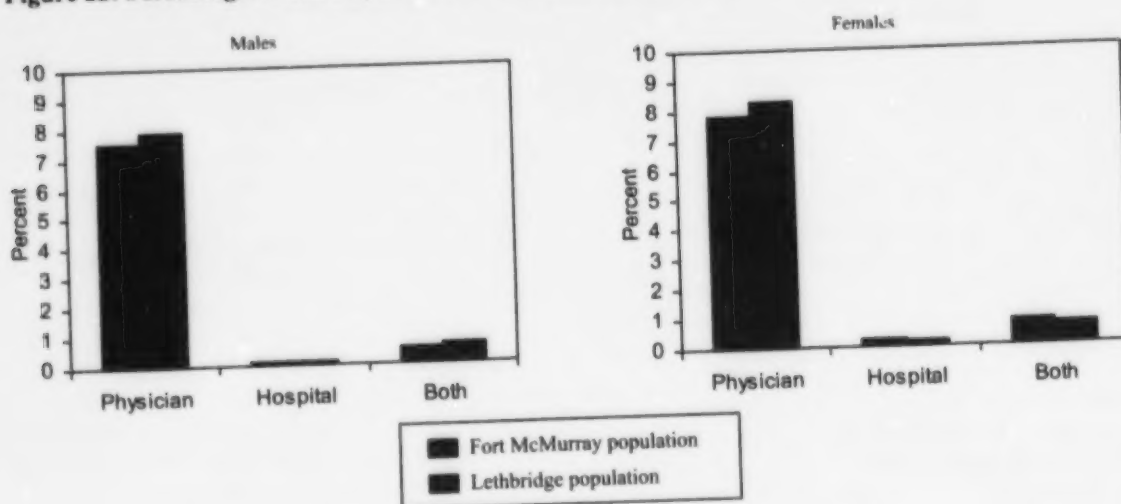


Figure 23 shows no increased risk of death for males and females in Fort McMurray, when compared to Lethbridge, from overall causes of death or death from lung cancer, cardiovascular diseases (CVD), coronary heart disease (CHD), respiratory disorders, or chronic obstructive pulmonary disease (COPD). This is shown by the overlap of the 95% confidence interval of the relative risk and the expected risk (one).



Figure 23: Relative Risk Ratio for Selected Causes of Deaths by Sex in Fort McMurray Compared to the Lethbridge Population

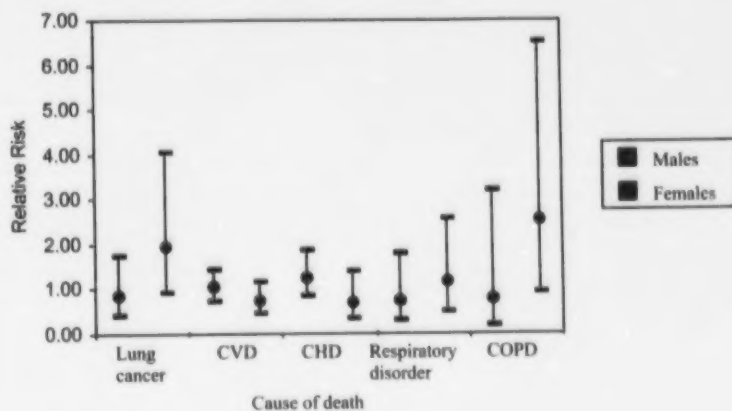
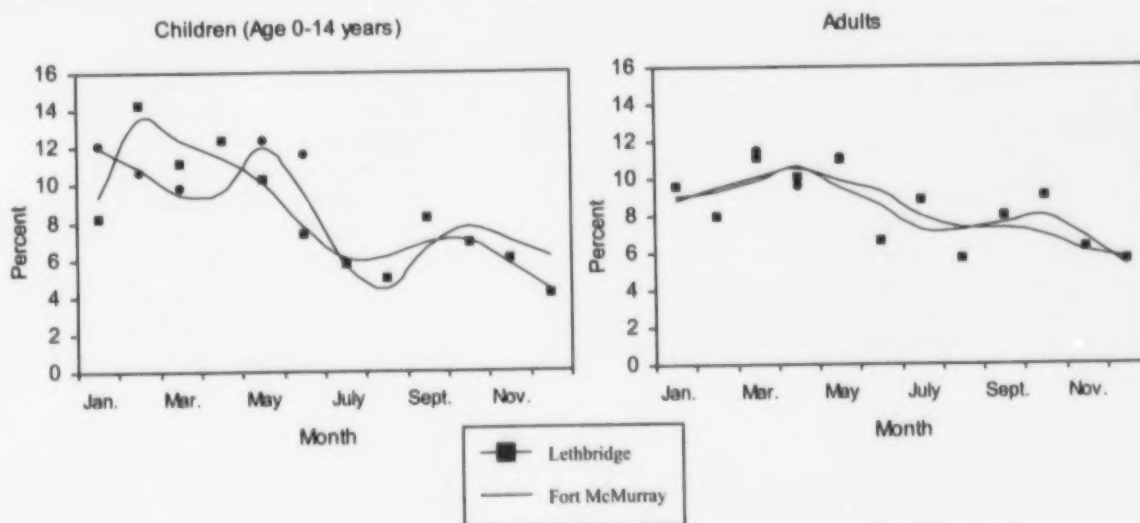


Figure 24 shows the seasonal variations of asthma morbidity in children and adults between the two communities.

Figure 24: Seasonal Variation of Asthma Morbidity - Fort McMurray Compared to Lethbridge





In summary, the overall findings from the analysis of health records were:

- Compared to the control community of Lethbridge, there is no evidence of either a significantly higher morbidity (incidence, prevalence, number of physician visits) of asthma and COPD in Fort McMurray, nor an increased risk of death from all causes, lung cancer, cardiovascular disease, coronary heart disease, respiratory disorders, or COPD in this area.
- There is no difference in overall illness between the study participants and non-participants, although the frequency of physician visits in some participant groups appeared to be higher.
- Seasonal variations in asthma morbidity (physician visits and hospitalization) were more pronounced in children and varied by study area. In Lethbridge, February is the highest and December is the lowest among children, while in Fort McMurray the corresponding months were May and August. Regional differences in seasonal patterns were more pronounced for children with an allergic form of asthma. No regional differences in seasonal patterns were found in the adult population.

12.0 Exposure Sources

An objective of the Main Study was to quantify the relative contributions of various exposure sources and pathways to airborne chemicals. This section of the report will discuss sources of exposure drawing on an analysis of wind and ambient air quality data and some of findings of the previous section that addressed exposure pathways. This assessment qualitatively compares the relative contributions of indoor vs. outdoor exposure sources and further categorizes the outdoor sources as local (urban emissions), regional (oil sands industry), and background (levels not due to regional industry or the city).

In exploring the impacts of regional contaminant sources, hourly data from the WBEA Athabasca monitoring station was analyzed for the time period of the study.

12.1 Sulfur Dioxide (SO_2)

Figure 25 shows a surface that represents the average of hourly SO_2 reading taken with the WBEA monitors at the Athabasca ambient station. As the figure shows, there were significantly higher average levels of SO_2 in the city of Fort McMurray when the wind was from the north (roughly 281 to 56 degrees) at moderate wind speeds (3 to 15 km/hr). The increase in SO_2 levels in the city when winds are from the north is likely due to SO_2 emissions from the oil sands plants that are located north of the city. The significant impact of local emissions of SO_2 is defined in the part of the figure that shows the wind from the south at low speeds. The impact of background levels was very low as is shown by the low concentration in the area of the figure with high wind speeds.

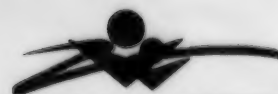
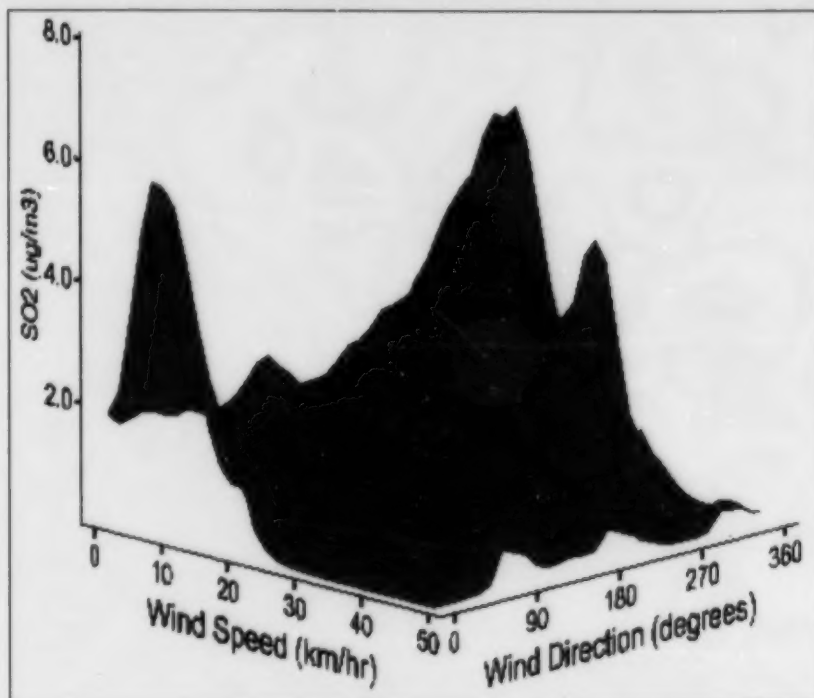


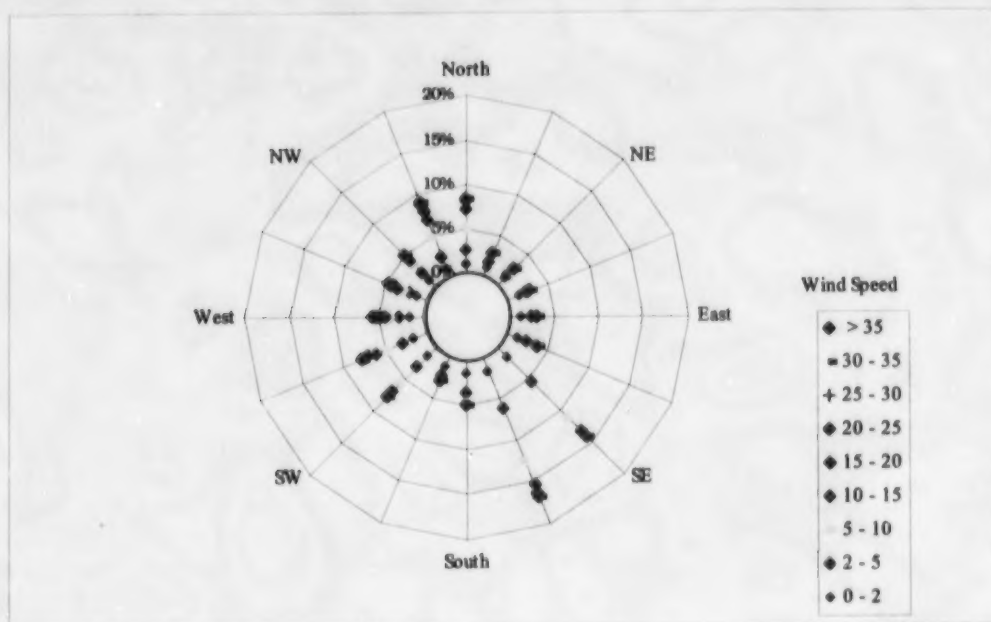
Figure 25: Average SO₂ Levels at Fort McMurray Measured by WBEA During Study (June 1997 to Dec. 1998) Plotted by Wind Speed and Wind Direction



The impact of the regional SO₂ sources north of the city on the average SO₂ levels in Fort McMurray was estimated. The estimate is based on an overlay of the SO₂ surface in Figure 25 and the wind diagram in Figure 26. The wind diagram describes the percent of time the wind blows from various directions and speeds. As the wind diagram shows the predominant wind direction during the study was from south-southeast and the average wind speed was 7.5 km/hr (data from WBEA).



Figure 26: Wind Diagram Showing Frequencies of Wind Speed and Direction Combinations



Estimates of SO₂ levels, unrelated to regional sources to the north of Fort McMurray, were based on average levels when the wind was from southern directions (102 to 213 degrees). Estimates of SO₂ levels attributable to the oil sands plants were based on the difference between estimated levels from southern sources and the estimated levels from northern sources (56 to 281 degrees). Estimates of the proportion of SO₂ contributed by source are as follows:

- Portion of SO₂ levels due to northern sources = 36% = (time weighted SO₂ levels due to northern sources) / (time weighted total SO₂ levels).
- Portion of SO₂ levels due to local or non-northern sources = 63% = (time weighted SO₂ levels due to non-northern sources) / (time weighted total SO₂ levels).

The SO₂ levels in Fort McMurray are significantly higher when influenced by northern sources. Based on wind speed and direction data, 36% of the average SO₂ concentrations in Fort McMurray were attributable to northern sources. This result is sensitive to wind direction. During this study the wind blew from the north roughly 25% of the time. If wind from the north increases in the future, it would be expected that the oil sands plants influence on the SO₂ levels would also increase. It should be kept in mind that these SO₂ levels are considered low.

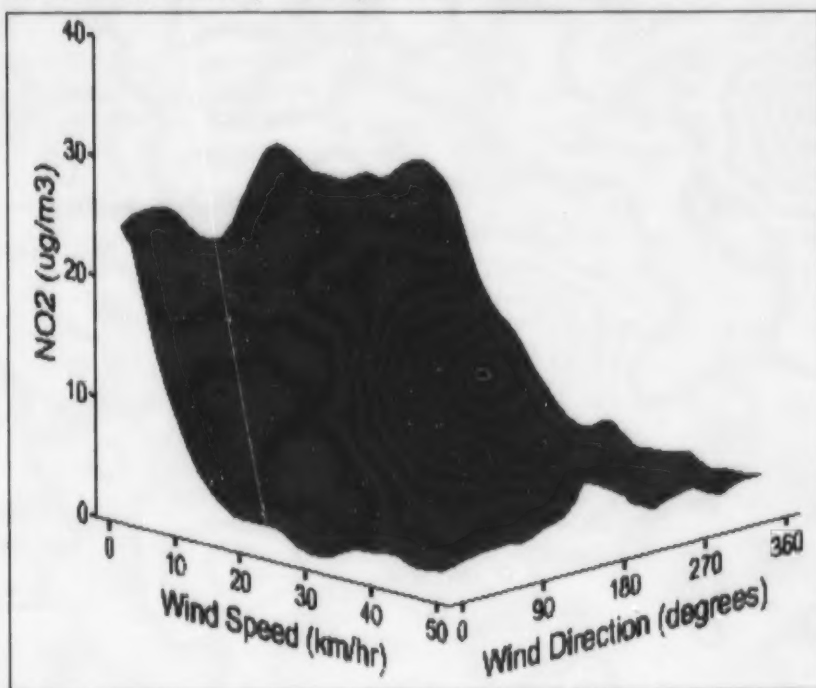
Section 7.2 identified outdoor levels of SO₂ as an important driver of personal exposure both directly and through indoor air. This analysis indicates that local urban emissions and oil sands plant emissions have a significant impact on the ambient SO₂ levels in Fort McMurray. Based on these findings, the most important exposure source identified during this study was local sources followed by regional sources while background influences could not be identified.



12.2 Nitrogen Dioxide (NO_2)

Figure 27 shows the average NO_2 levels during the period of study with the highest concentration of NO_2 occurring at low wind speeds consistent for all directions. The NO_2 concentrations in the figure indicate that ambient NO_2 levels in Fort McMurray are dominated by local sources with little influence of regional or background sources being evident.

Figure 27: Average NO_2 Levels at Fort McMurray Measured by WBEA During Study (June 1997 to Dec. 1998) Plotted by Wind Speed and Wind Direction



The analysis of NO_2 exposure pathways (section 7.1) showed both indoor and outdoor impacts on personal NO_2 exposures. The results identified outdoor levels of NO_2 as the more important driver and pathway of personal exposure. Based on these findings, local emissions of NO_2 were the largest exposure source identified while the influence of regional or background sources was not detected.

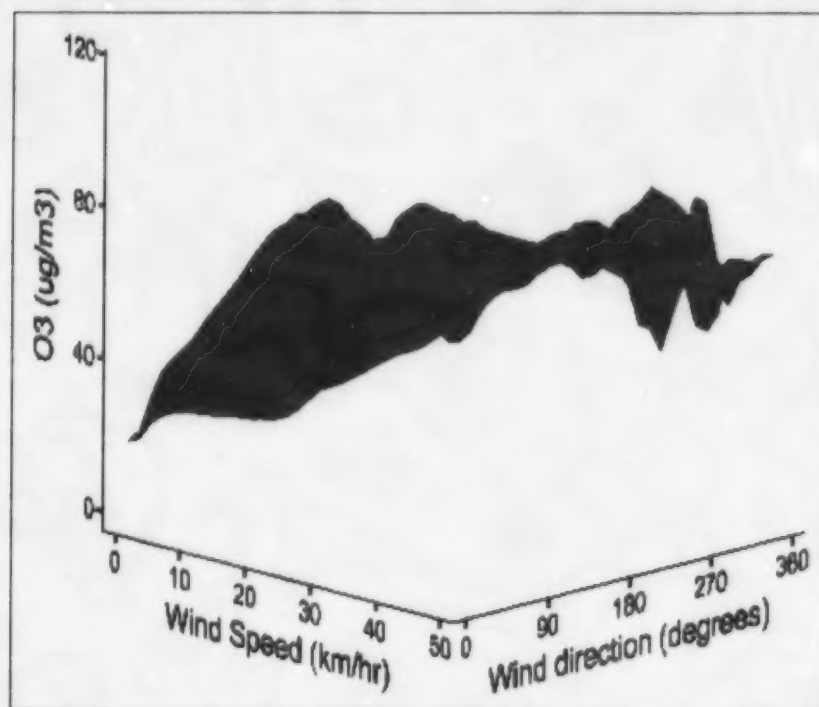


12.3 Ozone

Figure 28 shows the surface representing the average ozone levels during the study with highest levels of ozone occurred during higher wind speeds. These ambient levels did not predict personal exposures well (refer to section 7.3). This figure demonstrates the classic characteristics of ozone in urban areas where there are lower concentrations of ozone due to scavenging by urban pollutants during low wind speeds (low winds coincides with higher pollutant concentrations) and higher concentrations of ozone coincidental with lower urban pollution during high wind speeds. The figure does not demonstrate that the levels of ozone in Fort McMurray are significantly impacted by regional pollution sources, but it does suggest that local urban pollution was an important influence on the ozone levels.

The behavior of ozone in the environment is very complex making it difficult to draw succinct conclusions as to important exposure sources. This analysis indicates that outdoor air is the source of ozone in personal exposure and background sources are the most important relative source with regional and local sources not increasing personal exposure to ozone.

Figure 28: Average O₃ Levels at Fort McMurray Measured by WBEA During Study (June 1997 to Dec. 1998) Plotted by Wind Speed and Wind Direction





12.4 Particulate Matter ($PM_{2.5}$)

The analysis of exposure pathways for $PM_{2.5}$ demonstrated that outdoor concentrations were not a significant pathway for $PM_{2.5}$ exposures and that personal activities and indoor air were most important (section 7.5). The personal activity that was most important was time spent outdoors at the oil sands plants, which indicates higher levels of $PM_{2.5}$ in that environment. An analysis of the effect of wind direction on the mass concentration of $PM_{2.5}$ in samples collected for this study showed these higher $PM_{2.5}$ levels were not detectable in Fort McMurray samples (Figure 29). Based on these findings it is concluded that indoor air (and activities) are the most important exposure source while the influence of outdoor air (local, regional and background sources) were not detectable.

To further investigate the exposure sources of $PM_{2.5}$, an analysis was undertaken focusing on the composition of the $PM_{2.5}$. The analysis identified the percent vanadium in $PM_{2.5}$ as an indicator of oil sands industry sources. This was based on significantly higher $PM_{2.5}$ -bound vanadium exposures for people spending time at the plants and significant increases in the vanadium concentration in the ambient air $PM_{2.5}$ in Fort McMurray when the wind is from the north. Figure 30 shows the higher vanadium fraction of the $PM_{2.5}$ when the wind is from the north in personal, indoor, outdoor and ambient station samples though only the ambient samples were statistically significant. The data suggests that personal, indoor and outdoor $PM_{2.5}$ bound vanadium in Fort McMurray is also impacted from the oil sands plants although there were not enough samples to show significance. The results also suggested impacts on non-plant workers through ambient air, however there was insufficient data to conclude this with confidence. There is no indication that the levels of vanadium measured are a concern to human health.

In summary, the impacts of regional sources on the mass concentration of $PM_{2.5}$ in personal exposures were indistinguishable due to the numerous other factors affecting exposure. Using $PM_{2.5}$ -bound vanadium as an indicator of oil sands industry emissions of $PM_{2.5}$ enabled the identification of oil sands activity on the character of $PM_{2.5}$ in the ambient air in Fort McMurray and personal exposures of plant employees and suggested impacts on indoor air and exposure for all residents. This may be a useful indicator in future assessments as it may distinguish between local sources of particulate matter and industrial sources.



Figure 29: Average $PM_{2.5}$ Mass Concentration ($\mu g/m^3$) by Average Wind Direction During Sampling

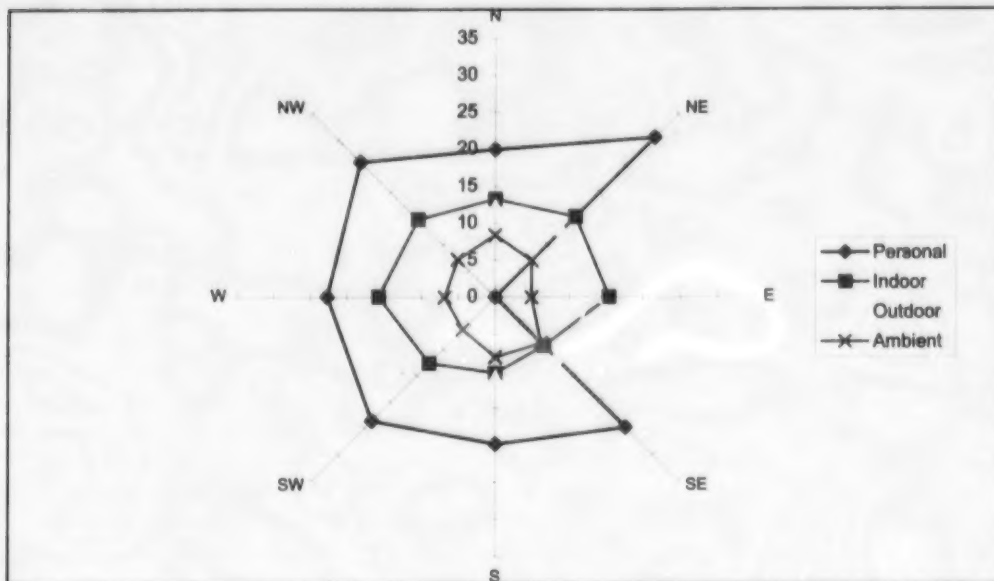
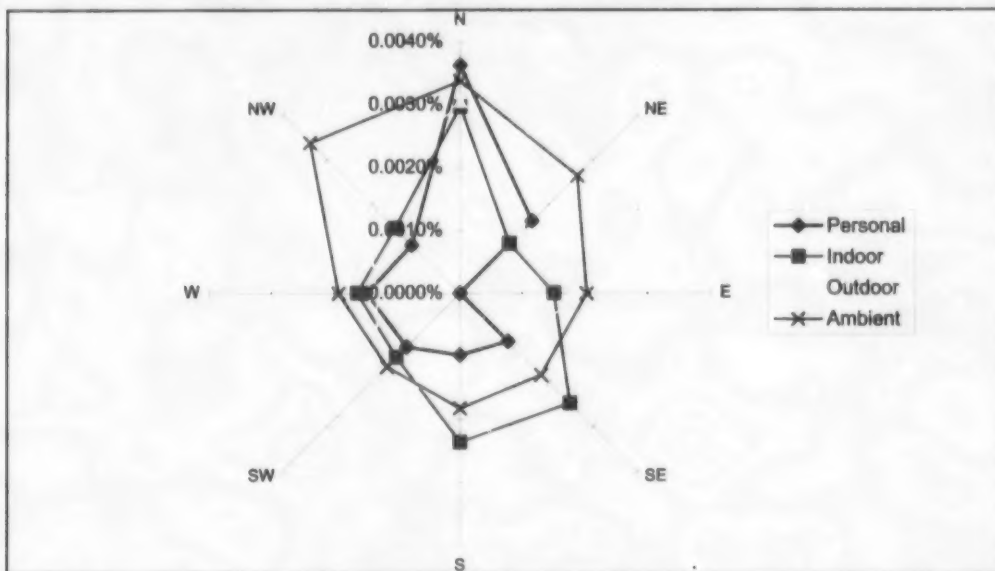


Figure 30: Percent Vanadium in $PM_{2.5}$ Compared to Average Wind Direction During Sampling





13.0 Conclusions

The Alberta Oil Sands Community Exposure and Health Effects Assessment Program was designed to establish possible links between air quality and human health outcomes. The study collected a wide range of self-reported measures of health using questionnaires, surveys, and administrative data. Exposure levels to airborne chemicals and particulates were measured in a variety of locations and the relative contribution of various exposure sources and pathways to airborne chemicals was estimated. Finally, associations between the exposure data and human health effects were described. The key findings of the study are presented in the following sections.

13.1 The Environment

The main industry within the Regional Municipality of Wood Buffalo is oil sands extraction and upgrading at Syncrude Canada, 44km north of Fort McMurray, and Suncor Energy, 34km north of the city. In addition to Syncrude and Suncor there are a number of other oil extraction plants, gas companies, and growing development in the forestry sector. The Athabasca Oil Sands deposit contains more oil than all the known reserves in Saudi Arabia. The region continues to experience rapid growth and development.

The Main Study investigated the influence of air concentration in the environment on personal exposure for a number of contaminants. A qualitative assessment of important exposure sources identified either indoor or outdoor air as the dominant source and further indicated the relative importance of local (urban emissions, regional sources (oil sands industry), and background sources.

For sulfur dioxide (SO_2), the most important exposure source identified was local sources followed by regional sources, while an influence from background sources and indoor sources was not detected. For nitrogen dioxide (NO_2), the most important exposure source was local sources, while influences from background and regional sources were not detected and the presence of indoor sources could not be confirmed. For ozone (O_3), the most important exposure source was background sources, while indoor, local, and regional influences that increase exposure were not detected. For particulate matter of $2.5\mu\text{m}$ ($\text{PM}_{2.5}$), in terms of mass concentration, the most important exposure source was personal activity and indoor sources, while influences from outdoor air (i.e., local, regional, and background sources) were not detected. In terms of PM character (composition), the study found a significant influence from the oil sands plants on the vanadium content of the $\text{PM}_{2.5}$, while local, background, and indoor sources did not influence vanadium composition.

13.2 The Population

Participants were recruited from Fort McMurray and the city of Lethbridge. Lethbridge was chosen as a control location due to the contrast of industries between the two cities. The populations of Fort McMurray and Lethbridge are 36,400 and 68,712, respectively. Although Lethbridge is considerably larger than Fort McMurray, both cities are considered medium sized within the province of Alberta.

Construction and analysis of the health records database provided insight as to the degree to which the study samples were representative of their populations in terms of overall illness and allowed for a comparison of rates of illness and death from selected diseases between Fort McMurray and Lethbridge.

Seasonal patterns in asthma morbidity (physician visits and hospitalization) were found to be more pronounced in children and varied by study area. In Lethbridge, February was the highest and December was the lowest month among children, while in Fort McMurray, May was the highest and August was the



lowest. Children with the allergic form of asthma were more likely to show regional differences in seasonal patterns, however, there were no regional differences found in seasonal patterns of asthma in the adult population.

There was no evidence of significantly higher morbidity (incidence, prevalence, number of physician visits) of asthma or COPD or of an increased risk of death from all causes, lung cancer, cardiovascular disease, coronary heart disease, respiratory disorders, or COPD in Fort McMurray compared to Lethbridge.

13.3 The Study Sample

Questionnaires received from 277 and 30 participants in Fort McMurray and Lethbridge, respectively, provided the data used for analysis. These reflected or correspond to the demographic profile of each community involved.

Analysis of the questionnaire data showed that the sample population adequately reflected the population distribution with respect to age, gender, education, and income. The Fort McMurray and Lethbridge samples appear to have attained high levels of education in comparison to census data. The average annual household income of the Fort McMurray sample was significantly higher than the Lethbridge sample. Fort McMurray's average annual household income is among the highest in Canada.

Despite reports that smoking prevalence in the Northern Lights Regional Health Authority is higher than the Canadian average, these higher rates of smoking were not reflected in the Fort McMurray sample.

Nutritional intake, body mass index, and physical activity were also examined using questionnaire data. There were no differences found in nutritional intake between Fort McMurray and Lethbridge. The average body mass index (BMI) for the two sample populations was higher than the estimated Canadian average, indicating a higher level of obesity in both sample populations. The Fort McMurray participants were significantly less active than the Lethbridge participants. Large proportions of the two samples do not get enough exercise according to Health Canada's recommendations, although both samples still surpass the provincial average of physical exercise.

The water samples collected from the Fort McMurray participants were all within any maximum allowable concentration guidelines. There is no evidence of health effects related to poor water quality from the samples collected.

13.3.1 Measures of Health

Several standardized questionnaires were included to obtain measures of the participant's perceived health, as well as measures of mental and psychosocial health. No statistically significant differences between the samples on any of the self-reported health questionnaires were identified. Previous diagnoses were very similar in the two samples. Any differences in previous diagnoses are most likely due to the small size of the Lethbridge sample. Fewer Fort McMurray participants (80%) reported having a diagnosis of a chronic condition compared to Lethbridge participants (87%). The most common diagnoses in Fort McMurray included: allergies (46%) and back problems (22.3%), while Lethbridge included: allergies (43%), asthma (27.6%), and arthritis (26.7%). There is no difference in overall illness between people who participated in the study and those who did not, although the frequency of physician visits in some groups of participants appears to be higher.



13.3.2 Biomarkers of Exposure

The biomarkers of exposure were included to provide evidence of exposure to a variety of contaminants that may have been greater than the general population. Nicotine levels were found to be independently related to the amount participants smoked, whether participants allowed smoking in the car, and to the number of test days participants were exposed to smoke. Very few individuals had appreciable urine levels of biomarkers for exposure to ethylbenzene or xylene. Biomarkers for benzene and toluene were found (muconic acid and hippuric acid, respectively), however, because personal exposure levels were all very low, the relationship between personal exposure and urine biomarkers was not strong enough to be statistically significant.

13.3.3 Biomarkers of Effect

The biological measures of effect were evaluated to provide evidence of any chronic conditions that may have been present in greater frequencies than the general population. The percentage of samples that were positive for autoantibodies are comparable to findings in the literature for normal, healthy populations, and there are no significant differences between the Fort McMurray and Lethbridge samples. The Fort McMurray and Lethbridge samples were within referent ranges for overall lung function and no statistically significant differences were found between groups. No statistically significant differences in neurocognitive functioning were found between the samples or in comparison to reference populations, except that the participants in Fort McMurray performed significantly better on a test of motor speed (finger tapping).

13.4 Measures of Exposure

The exposure model, represented by Figure 9, was developed as an attempt to describe the effects of the variability of a series of nine groups of factors on variation in personal exposure. Data analysis involved multi-step regression analysis designed to isolate and quantify the direct and indirect effects of the factors. These nine factors are: 1) gender; 2) housing; 3) job status; 4) smoking; 5) seasonal effects; 6) time activity; 7) exposures; 8) indoor; and 9) outdoor.

The following describes the major findings of the air quality investigation both in terms of the concentrations measured and the factors affecting the variations in personal exposure. Detailed findings are presented in the *Technical Report*.

13.4.1 Nitrogen Dioxide (NO₂)

Levels were low compared to existing guidelines and were comparable to other similar studies. The order of locations from highest to lowest median concentrations were personal (15.1 µg/m³), ambient (10.8 µg/m³), outdoor (9.5 µg/m³), and indoor (8.6 µg/m³). The final model predicted about 40% of the variation in personal NO₂ exposure across individuals and days. Overall, variability across seasons accounted for over one-third of the variation in personal exposure described by the model. Variation in outdoor and indoor levels each accounted for roughly one-quarter of the variation in personal exposure. Time activity was also important. Seasonal variation had a significant influence on personal levels. Seasonal variation exerted its largest influence through its effects on outdoor concentrations, time activity, and indoor concentrations but did not directly influence personal levels to a great extent. As noted above, personal exposures were higher than those measured either indoors or outdoors. The amount of time spent indoors at locations other than home (i.e., work) was identified as important and explains the higher personal exposures.



13.4.2 Sulfur Dioxide (SO₂)

Indoor and ambient levels were very low compared to existing guidelines. The order of locations from highest to lowest median concentrations were ambient (2.0 $\mu\text{g}/\text{m}^3$), outdoor (1.6 $\mu\text{g}/\text{m}^3$), personal (0.87 $\mu\text{g}/\text{m}^3$), and indoor (0.41 $\mu\text{g}/\text{m}^3$). The final model predicted about 25% of the variation in personal SO₂ exposure across individuals and days. Overall, variations in indoor levels across houses (under the influence of outdoor levels) and temporal variability of outdoor levels account for roughly three-quarters of the variation in personal exposure explained by the model. Note that this does not necessarily mean that there were indoor sources of SO₂, rather it likely means that the differences between houses resulted in different SO₂ levels. Outdoor levels, indoor levels under the influence of outdoor levels, and time activity were important factors affecting personal exposure.

13.4.3 Ozone (O₃)

Indoor and personal levels of ozone were very low. Outdoor and ambient levels were an order of magnitude higher. This suggests that ambient measures are an inadequate measure of personal exposure. The order of locations from highest to lowest median concentrations were ambient (50 $\mu\text{g}/\text{m}^3$), outdoor (39 $\mu\text{g}/\text{m}^3$), personal (3.3 $\mu\text{g}/\text{m}^3$), and indoor (2.4 $\mu\text{g}/\text{m}^3$). The final model predicted about half of the variation in personal O₃ exposure across individuals and days. The majority of variations in personal exposure described by the model were due to indoor concentrations that were heavily influenced by seasonal effects (lower concentrations in winter) and influenced to a lesser degree by outdoor concentrations. Overall, indoor levels explained over 30% and outdoor levels explained less than 5% of the variance in personal O₃ levels. Seasonal variation was an important effect that appears to impact personal exposure almost independently of outdoor concentrations (i.e., by affecting time activity, specific exposures and indoor concentration). It cannot be over emphasized that outdoor concentrations were not a good surrogate measure of personal exposures in this study. Personal levels were only 10% of outdoor levels and changes in outdoor concentrations accounted for less than 5% of the variation in personal exposures.

13.4.4 Volatile Organic Compounds (VOCs)

The final model predicted about 40% of variation in personal VOCs exposure across individuals and days. The order of locations from highest to lowest median concentrations were personal (2.8 $\mu\text{g}/\text{m}^3$), indoor (1.7 $\mu\text{g}/\text{m}^3$), outdoor (1.3 $\mu\text{g}/\text{m}^3$), and ambient (1.2 $\mu\text{g}/\text{m}^3$) for benzene. Indoor concentrations were the predominant factor affecting personal exposure; the other factors were of only minor relative importance. This suggests that exposure to these chemicals was predominantly from sources affecting indoor levels. Outdoor concentrations did not have a significant direct effect on personal exposure but had a small indirect effect through indoor air accounting for about 2% of the variance in personal exposure. Additional investigations during the study located high VOCs concentrations in some house garages and at service stations.

13.4.5 Particulate Matter 2.5 μm (PM_{2.5})

The final model predicted about 75% of variation in personal PM_{2.5} exposure, but there is greater uncertainty in this estimate due to the limited number of samples. The order of locations from highest to lowest median concentrations were personal (25 $\mu\text{g}/\text{m}^3$), indoor (8.6 $\mu\text{g}/\text{m}^3$), outdoor (8.4 $\mu\text{g}/\text{m}^3$), and ambient (6.2 $\mu\text{g}/\text{m}^3$). Time activity, smoking, and job status were important factors affecting PM_{2.5} exposures accounting for roughly two-thirds of the variation explained by the model. Indoor concentrations had an important impact on personal exposures both directly and as a pathway through



which other factors act (about 12%). Outdoor concentrations were not important as either a driver or a pathway of personal exposure.

13.4.6 Particulate Matter 10 μ m (PM₁₀)

The final model predicted about 65% of variation in personal PM₁₀ exposure, but there is greater uncertainty in this estimate due to the limited number of samples. The order of locations from highest to lowest median concentrations were personal (57.3 μ g/m³), ambient (15.2 μ g/m³), indoor (15.1 μ g/m³), and outdoor (12.4 μ g/m³). Smoking characteristics, job status, and specific exposures were important factors affecting PM₁₀ personal exposures, accounting for roughly three-quarters of the variation explained by the model. Indoor and outdoor levels were responsible for less than 5% of the variance in personal PM₁₀. Important factors influencing variation in personal exposure did not exert effects through indoor and outdoor concentrations. Ambient concentrations were not a good predictor of personal exposures.

14.0 Discussion

"A series of new studies over the past decade have demonstrated a link between ambient air pollution and several adverse human health effects..."⁶⁵

"It is critical to our understanding of health and the environment that we have credible information. Continuing to improve our exposure assessment is the key to understanding this relationship ... the goal of such studies (i.e., personal exposure) is to gather sound scientific evidence based on the best possible technology." (Gabos, 1998)

There is ample evidence in the peer-reviewed literature that epidemiological studies (i.e., ecological studies) have been used to establish a correlation between ambient air quality and human health outcomes. However, there is little evidence of a causal relationship. Furthermore, there is very little conclusive evidence that demonstrates the contribution to personal exposure from indoor and outdoor sources.

The strength of these ecological studies is that they provide evidence of an association between ambient air quality and human health. However, their weakness relates to judgements regarding causality; they lack the direct link between personal exposure to a contaminant and the resulting human health outcome. They also fail to tell us anything about individual exposure or individual risk.

Many previous exposure studies have relied on data from static ambient air monitoring stations to represent population exposure contaminants. It is clear from the Alberta Oil Sands Community Exposure and Health Effects Assessment Program experience that air quality data recorded at these static ambient monitoring stations does not represent, and should not be interpreted as representing, personal exposure to the contaminants being monitored. If we are to better understand the relationship between air quality and human health outcomes, it is clear that personal exposure monitoring must become part of an enhanced long-term air monitoring strategy.

This approach (i.e., personal exposure monitoring) has been recognized by the Clean Air Strategic Alliance* (CASA), and by the Alberta Multi-Stakeholder Group on Particulate Matter and Ozone** (MSG-PM/O₃). CASA's Human Health Project Team developed a comprehensive air quality and human health monitoring framework that recognizes and supports establishing a long-term, systematic approach to data gathering, focused on improving our knowledge about the link between air quality and human health. The components of the comprehensive human health and air quality monitoring system include:



- Symptoms and public health complaints;
- Known human health effects of air contaminants;
- Information about relevant event occurrences;
- Ambient air quality monitoring data; and
- Human health effects monitoring data.

Recommendations from the MSG-PM/O₃ to Alberta Environment included the recommendation that: "personal exposure monitoring should become part of a long-term air monitoring strategy in any region within the country and these efforts should be encouraged and supported. Personal exposure monitoring data will help us better understand the relationship between air quality and human health outcomes."

These initiatives, together with the Alberta Oil Sands Community Exposure and Health Effects Assessment Program, recognize that data gaps currently exist that limit our understanding of the relationship between air quality and human health outcome. These include:

- Identification of the responsible component(s) of air quality that is causally associated with adverse health effects;
- A description of the population and personal distribution of exposure to airborne chemicals and particulates; and
- An understanding of the relative contribution of various exposure sources and pathways to airborne chemicals (i.e., the relative contribution of outdoor and indoor air to the total exposure).

Recently, the National Environmental Respiratory Center (NERC) indicated support for addressing these data gaps. It states that, "environmental air quality research and regulatory strategies have focused largely on single pollutants and sources, but it is unlikely that the health effects observed in individuals or populations are caused solely by single pollutants or sources. Indeed, as levels of most air pollutants are reduced, it is unlikely that the residual effects observed in populations are attributable to a single pollutant species or sources. There is an increasing need to know more about the contributions of individual pollutants and families of pollutants to the total effects of exposure to complex mixtures of air contaminants from man-made and natural sources. There is also a great need to better understand the health risks caused by interactions between exposures to environmental pollutants and to airborne materials encountered in the home and workplace."

There is clearly a need to encourage others to develop and participate in activities that are consistent with the terms of reference and experience of the Alberta Oil Sands Community Exposure and Health Effects Assessment Program:

- Describe the population and personal distribution of exposure to airborne chemicals and particulates:
 - estimate the population distribution of selected airborne chemicals and particulates;
 - estimate the seasonal variation of exposure; and
 - characterize the personal variation of exposure as a function of individual activity patterns.
- Quantify the relative contribution of various exposure sources and pathways to airborne chemicals:
 - quantify the relative contribution of outdoor and indoor air to the total exposure.
- Describe associations between exposure to airborne chemicals and human health effects:



- analyze occurrence relationships between selected exposures, biomarkers and health outcomes.

* The mandate of the Clean Air Strategic Alliance is to bring together diverse stakeholder groups to solve air quality problems on a consensus, rather than adversarial, basis.

** The Multi-Stakeholder Group on Particulate Matter and Ozone provided recommendations to Alberta Environment related to the Canada Wide Standard process addressing Particulate Matter and Ozone.



15.0 Abbreviations

AEP – Alberta Environmental Protection

AHCIP – Alberta Health Care Insurance Plan

ALPAC – Alberta-Pacific Forest Industries Inc.

ANA – antinuclear antibodies

AO – aesthetic objective

BTEX – benzene, toluene, ethylbenzene, and xylenes

BMI – body mass index

CASA – Clean Air Strategic Alliance

CHD – coronary heart disease

COPD – chronic obstructive pulmonary disease

CVD – cardiovascular disease

DNA – deoxyribonucleic acid

FEV₁ – forced expiratory volume in one second

FVC – forced vital capacity

GHQ – General Health Questionnaire

I/O – ratio of indoor exposure to outdoor exposure

L – litres

MAC – maximum allowable concentration

MDL – method detection limit

MSG-PM/O₃ – Alberta Multi-Stakeholder Group on Particulate Matter and Ozone

N – number of cases overall

NERC – National Environmental Respiratory Centre

NES2 – Neurobehavioral Evaluation System

NIS – Neuropsychological Impairment Scale

NLRHA – Northern Lights Regional Health Authority

NO₂ – nitrogen dioxide

O₃ – ozone

PEP – Production Enhancement Phase

P/I – ratio of personal exposure to indoor exposure

PM_{2.5} – particulate matter of 2.5 microns or less (approximately 1/20 the diameter of a human hair); also called fine particles



PM₁₀ – particulate matter of 10 microns or less (approximately 1/6 the diameter of a human hair)

P/O – ratio of personal exposure to outdoor exposure

RHA – Regional Health Authority

SD – standard deviation

SES – socioeconomic status

SO₂ – sulfur dioxide

TEAM – Total Exposure Assessment Methodology

UK – United Kingdom

USEPA – United States Environmental Protection Agency

VOCs – volatile organic compounds

WBEA – Wood Buffalo Environmental Association

WMS-R – Wechsler Memory Scale – Revised

16.0 Definitions

Antinuclear antibody (ANA)

- an antibody that reacts against components of the cell nucleus such as DNA, RNA, histone, or non-histone proteins.
- these antibodies are present in a variety of immunologic or autoimmune diseases including systemic lupus erythematosus, systemic sclerosis, scleroderma, Sjogren's syndrome, rheumatoid arthritis, polymyositis, dermatomyositis, and in persons taking hydralazine, procainamide, or isoniazid.
- biological tests for antinuclear antibodies can aid in the diagnosis of unexplained arthritis, rashes, or chest pains.

Background sources

- sources responsible for the background levels of the contaminant (i.e., unimpacted by local and regional sources).
- these may include long-range transport of human-created sources and local/regional natural sources

Benzene⁶⁷

- a water-soluble volatile organic compound (VOC) which at normal temperatures is a liquid, but readily evaporates and small amounts are detectable in the atmosphere.
- important sources are the combustion of petroleum fuels by motor vehicle engines and emissions associated with many industrial activities such as ore mining, wood processing, coal mining, textile manufacture, and processes used in the oil and gas industry.
- other sources, of which cigarette smoking is a major one, make important contributions to the exposure of individuals.



- benzene is a known carcinogen and appears on Health Canada's First Priority Substances List.

Biomarker

- a specific biochemical in the body which has a particular molecular feature that makes it useful for indicating environmental exposure, the progress of disease, or the effects of treatment.

Body mass index (BMI)

- a measure of body mass; it has the highest correlation with skinfold thickness or body density.

BTEX compounds

- the BTEX chemicals (benzene, toluene, ethylbenzene, and xylenes) are volatile organic compounds (VOCs) which are commonly found together in crude petroleum and petroleum products such as gasoline.
- they are also produced as bulk chemicals for industrial use as solvents and starting materials for the manufacture of pesticides, plastics, and synthetic fibres.

Empirical

- based on experiment and observation.

Ethylbenzene

- a water-soluble volatile organic compound (VOC)
- ethylbenzene is used primarily in the production of styrene; other uses include solvents in paints and varnishes, as products in synthetic rubber, household cleaning products, gasoline, pesticides, carpet glues, asphalt, and tobacco smoke.
- ethylbenzene will enter the atmosphere primarily from emissions and exhaust connected with its use in gasoline; more localized sources will be emissions, waste water, and spills from its production and industrial use.

Local sources

- human-created sources of a contaminant originating from within the city of Fort McMurray.
- these include emissions from vehicles, home heating, and industries within the city.

Median

- the value halfway through the ordered data set, below and above which there lies an equal number of data values.

Method detection limit (MDL)

- the minimum concentration that can be measured and reported with confidence that the value is above zero -- that is, that the contaminant is actually present
- in this study, three standard deviations above the mean method blank levels were used as the MDL.



Morbidity

- the condition of being diseased or sick; a state of ill-health.

Nitrogen dioxide (NO₂)⁶⁸

- for the purposes of air quality monitoring, oxides of nitrogen (NO_x) is considered to be the sum of nitric oxide and nitrogen dioxide; most oxides of nitrogen are emitted in the form of nitric oxide which will rapidly react with ozone in the atmosphere to form nitrogen dioxide.
- in Alberta, about 43% of oxides of nitrogen emissions are produced by transportation (primarily by vehicles), while 37% are due to industrial sources (oil and gas industries) and 18% as a result of power plants (based on 1990 emission estimates).
- smaller sources of oxides of nitrogen include natural gas combustion, heating fuel combustion, and forest fires.

Ozone (O₃)^{69, 70}

- ozone is both a naturally occurring gas, generated in the higher layers of the atmosphere and a major constituent of photochemical smog.
- unlike other pollutants, ground-level ozone is not emitted directly by man's activities, but is generated by a photochemical reaction of oxides of nitrogen (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight.
- in Alberta, ozone concentrations are generally lower at urban locations than at rural locations due to the destruction of ozone by nitric oxide which is emitted by vehicles.
- in Alberta, maximum ozone values are generally recorded during the spring and summer months.

Particulate Matter (PM)⁷¹

- particulate matter consists of a mixture of particles of varying size and chemical composition.
- most man-made particles are in the range of 1 to 10 microns in diameter; particles less than 10 micrometers in diameter (PM₁₀) are considered to be inhalable particulates and are suspended in the air for an indefinite period of time.
- PM₁₀ sources, which can be inhaled into the nose and throat but do not normally penetrate into the lungs, include windblown soil, road dust, dust resulting from other activities (e.g. harvest), and industrial processes, generally created during burning processes, consisting of fly ash from power plants, carbon black from diesel and gasoline engines, and soot from wood-burning.
- the fine particles (PM_{2.5} and less), which can penetrate into the lungs (respirable particulates), are typically secondary aerosols that form when chemical reactions occur between sulfate (from power plants) or nitrate (from motor vehicles and industry such as oil and gas plants) and ammonia or from sources such as compressor stations, household heating appliances, and forest fires.

Regional sources

- human-created sources of a contaminant in the region outside of the city of Fort McMurray.
- these include industries outside of the townsites such as the oil sands industries.



Relative Risk

- ratio of at-risk to non-risk individuals in a group.

Spirometry

- a measurement of the flow rates of air during certain points of the respiratory (breathing) cycle.
- together with lung volume measurements, spirometry allows for the identification of obstructive and restrictive lung diseases.

Sulfur dioxide (SO₂)^{72, 73}

- a water-soluble irritant gas and a major pollutant in the atmosphere formed during the processing and combustion of fossil fuels containing sulfur, for example from gas plant flares, oil refineries, pulp and paper mills, fertilizer plants, coal-fired power plants, power generating stations, metal smelters, and heating boilers.
- sulfur dioxide (along with NO_x) has a number of other environmental effects including lake acidification due to acid rain, and associated corrosion of stone and metalwork.
- sulfur reacts in the atmosphere to form sulfuric acid and acidic aerosols which contribute to acid rain; combines with other gases to produce aerosols which may reduce visibility causing haze over large regions.
- in Alberta, it is estimated that 42% of sulfur dioxide emissions are emitted by natural gas processing plants while oil sands and power plants produce about 26% and 18%, respectively, based on 1990 emission inventory; other sources in Alberta include gas plant flares, oil refineries, pulp and paper mills, and fertilizer plants.

TEAM

- method developed by the USEPA to determine exposures of the general population to certain pollutants (see the *Technical Report* for further detail)

Toluene

- a water-soluble volatile organic compound (VOC).
- the largest chemical use for toluene is in the production of benzene and urethane; also used as a solvent, gasoline additive, and in the manufacture of explosives, dyes, cements, spot removers, cosmetics, antifreezes, asphalt, and detergent.
- toluene is released into the atmosphere principally from the volatilization of petroleum fuels and toluene-based solvents and thinners, and from motor vehicle exhaust.
- toluene appears on Health Canada's First Priority Substances List.

Volatile organic compounds (VOCs)

- VOCs are chemicals that contain the element carbon.
- VOCs produce vapours readily; at room temperature and normal atmospheric pressure, vapours escape easily from volatile liquid chemicals.
- VOCs include gasoline, industrial chemicals such as benzene, solvents such as toluene and xylene, and tetrachloroethylene (perchloroethylene, the principal dry cleaning solvent).



- VOCs can be emitted naturally or as by-products of industrial processes.

Wood Buffalo Environmental Association

- the Wood Buffalo Environmental Association (WBEA) is a collaboration of communities, industry, and government in the Regional Municipality of Wood Buffalo.
- primary objective is to monitor the ambient environment in a manner, which is transparent and open to scrutiny by all interested stakeholders.
- the WBEA produces monitoring results, allowing for effective environmental management of emissions in the Wood Buffalo region.⁷⁴

Xylene

- a water-soluble volatile organic compound (VOC)
- found in coal and wood tar, and crude wood spirit; used primarily as solvents for which their use is increasing as a replacement for benzene and in gasoline.
- major environmental releases of xylenes are due to emissions from petroleum refining, gasoline, and diesel engines.
- xylene appears on Health Canada's First Priority Substances List.



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Management Committee

The Management Committee was responsible for providing overall direction to the program to ensure that the objectives and intent of the program were carried out. The participating organizations are currently represented by:

Alberta Health and Wellness	Alexander MacKenzie
Community of Fort McMurray (member at large)	Debbie White
Fort McKay First Nation	Ken Shipley
Fort McMurray Environmental Association	Ann Dort-McLean
Northern Lights Regional Health Services	Dalton Russell
Suncor Energy	Tim Gondek
Synchrude Canada	Dr. Ken Nickerson

Operations Committee

The Operations Committee was responsible for managing the affairs of the program between meetings of the Management Committee. The Operations Committee included representatives from the following organizations:

Alberta Health and Wellness	Alexander MacKenzie
Community of Fort McMurray (member at large)	Debbie White
Northern Lights Regional Health Services	Patricia Pelton

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